Counting Carbon: Evaluating the Quality and Environmental Impacts of Design Through Product Prototyping

by

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A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Master of Architecture

Waterloo, Ontario, Canada, 2022

Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Industrialisation has brought numerous advancements to the architecture and design fields, many of which have allowed humanity to produce more efficiently, using less energy and human labour. Simultaneously, mass production has resulted in mass overconsumption, a populous that is disconnected from the origins of their belongings, and a planet whose resources and atmosphere have been propelled out of equilibrium. The primary consistent numeric metric available for evaluating a good design is its cost, which often leaves consumers to rely on appearance and the opinions of others to make buying decisions. This project creates a system for designers to evaluate and then improve the carbon emissions of prototypes, in conjunction with a universal graphic that clearly communicates this evaluation to consumers in a consistent way. The system uses carbon as a base value to convey the energy expended in the production of a product. It uses a scoring system to rate the design's adaptability, maintainability, and reliability—three indicators of overall longevity. This evaluation system combined with experimental prototypes demonstrates the possibility of standardised sustainable design by assessing products under a unified set of parameters. It seeks to remind people to revere objects as things to be repaired, not replaced, and advocates for a better balance between the environment we inherit and the commodities we manufacture.

Acknowledgments

My deepest thanks to the following:

To the Waterloo School of Architecture for giving me the freedom to explore a topic of my choosing.

To my advisor, David Correa—your continuous advice and wealth of knowledge helped give this thesis structure. Your encouragement made it possible for me to peruse this topic and keep building under unusual circumstances. Your views on process, materials, and documentation have made a lasting impression.

To my committee member, Jane Mah Hutton—your thoughtful questions brought depth and clarity to the work, aiding me in addressing the bigger picture.

To my internal reader, Heinz Koller— I missed being in the Waterloo workshop, but sincerely appreciate you reviewing this work from the perspective of industrial design and carpentry.

To my extremal reader, Christopher Romano—thank you for your contribution to the discussion and for traveling to see the pieces in person. I enjoyed both your questions and comments on the project.

To my Mother and Father, Mike and Joanne, whose support and collection of tools made it possible to complete this work during a pandemic.

With remote learning, this project was conducted in many places including Toronto, Montreal and Minden. I am so grateful to old and new friends in all these places for giving me a healthy environment to work in.

Thank you to my friends at Waterloo, both those who are in the undergraduate and graduate program. Special thanks to those who have spread out across the world but still find time to discuss or edit this work, I value your thoughts greatly.

Thank you to the other makers in this project, especially those who were willing to share information about their products origins. To the makers I personally met: speaking with you about the project was a highlight of the material sourcing process.

Lastly, thank you to the nonhuman actors of this project: to the forests I got to spend time in and the tress this project is built from, I am incredible grateful and amazed by the Canadian landscape.

Dedication

To the future generations of makers

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Preface

I have always had a deep curiosity for how things are made, constantly taking things apart and questioning their constitution. Many of my peers and I feel the mounting pressure of the climate crisis and are unsure what effect our personal decisions can have on such a significant global problem. This thesis is rooted in the desire to illustrate the value of a well-made object, to better understand the consequences of my decisions as a designer, and to make in such a way that limits harm to future life on this planet.

While I am not a stranger to tools and making, I began this thesis without a formal background in carpentry, electronics, or environmental sciences. In prior years of architectural study, I have developed a base knowledge of building design and how one considers the social, political, environmental, and economic challenges of a site. I believe what architecture fosters is the ability to think about different scales—from global systems to intricate details of a building assembly. We must consider various scales to problem solve. My process has involved a high degree of interchange between global and small-scale problems. I find myself motivated by these far-reaching problems and more engaged with the minute. The small scale provides the structure for exploration and the possibility to relate the work to the larger problems of the world.

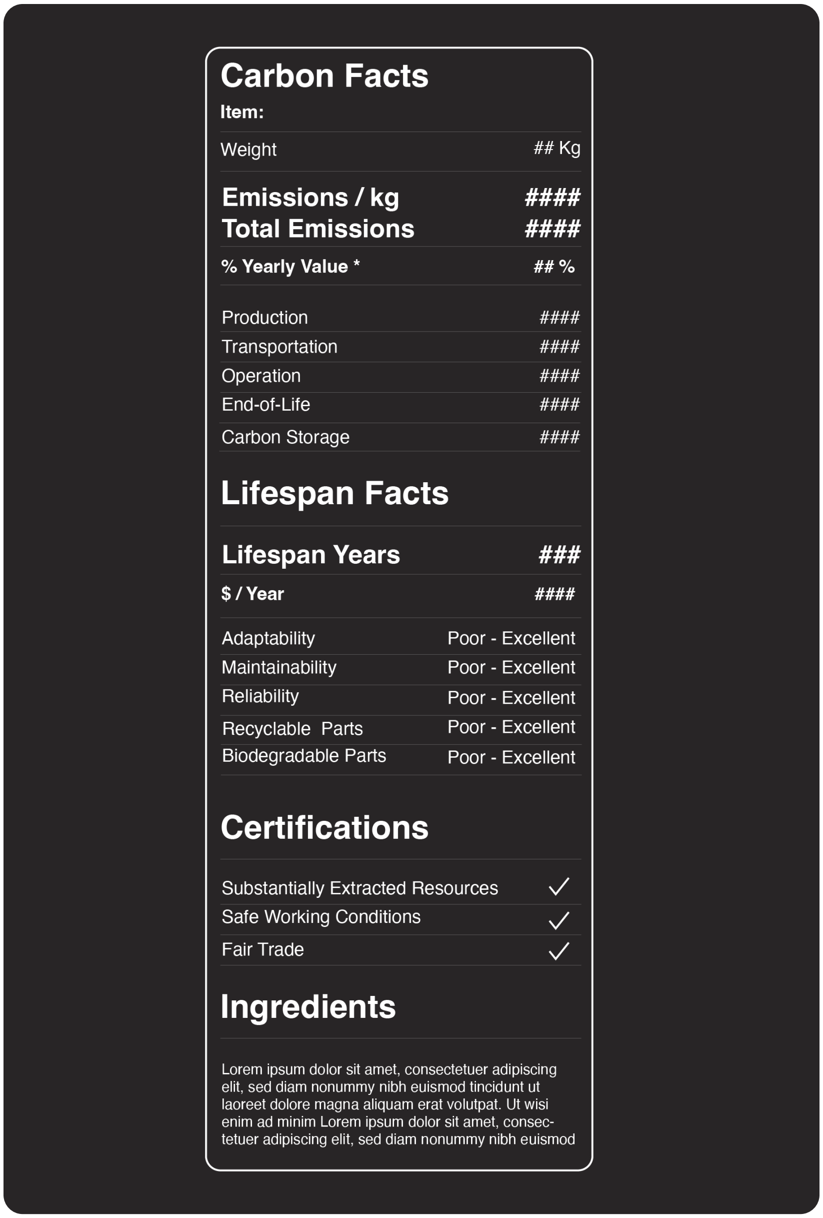
In both the news and advertising of late, I notice increasing debate around climate change and what the public, governments, and companies should do in response. Companies use green advertising to entice the next generation of consumers to buy their products, and there is little to no regulation on the claims these companies make. Even in the context of architectural education, I learned many strategies for environmentally-conscious design, but I always craved more quantitative information with which to weigh the impact of one's design decisions.

At its core, this thesis is a design-build furniture project that acts as a proof of concept for labelling carbon emissions associated with the architecture and design industries. Through prototyping and sourcing materials for novel objects, while simultaneously investigating the current methods for assessing environmental design, my research brings me into direct conversation with the challenges designers currently face. This project allows me to investigate making while learning about the challenges and realities of global carbon emissions. The acts of physically making something and accounting for carbon emissions are often at odds with one another. The designer and the environmentalist in me occasionally agree, but more often than not they are orchestrating an internal conflict. Neither the prototypes nor the labels are perfect, but I believe that the act of design is a richer experience with the addition of carbon accounting data. Transforming designs into tangible objects and estimating their carbon emissions expands the design process, adding priceless value to the pieces. The work is intended to contribute to a conversation about how the architecture and design industries communicate their process work to a larger community and how we can enable ethical design by sharing information through standard metrics.

Project Introduction

1.

Section Contents



Carbon Facts

Item:

Weight	## Kg
Emissions / kg	**####**
Total Emissions	**####**
% Yearly Value *	**## %**
Production	####
Transportation	####
Operation	####
End-of-Life	####
Carbon Storage	####

Lifespan Facts

Lifespan Years	**###**
$ / Year	**####**
Adaptability	Poor - Excellent
Maintainability	Poor - Excellent
Reliability	Poor - Excellent
Recyclable Parts	Poor - Excellent
Biodegradable Parts	Poor - Excellent

Certifications

Substantially Extracted Resources	✓
Safe Working Conditions	✓
Fair Trade	✓

Ingredients

Lorem ipsum dolor sit amet, consectetuer adipiscing elit, sed diam nonummy nibh euismod tincidunt ut laoreet dolore magna aliquam erat volutpat. Ut wisi enim ad minim Lorem ipsum dolor sit amet, consectetuer adipiscing elit, sed diam nonummy nibh euismod

Illustration.1 *Black Carbon Fact Label - Graphic by Author*

> ***“Nowadays people know the price of everything and the value of nothing.”***
>
> Oscar Wilde,
> *The Picture of Dorian Gray*

Chapter 1 - Project Introduction

Cost has become the dominant determinant of value. The word cost is frequently used to describe price, i.e., monetary value. Cost is alternatively defined as “a loss or penalty incurred especially in gaining something”. Thinking about the penalties of a purchase seldom goes beyond the loss of money. Value is a complex concept, and can be broken down and analysed in three categories: societal value, economic value, and linguistic value (Graeber, 2001). The tension between economic value and societal value comes to the forefront of this project, as design decisions are made based not only on economic factors but also on the quantification of social values in the making of products for consumption. Societal value relates to what we think “is ultimately good, proper, or desirable in human life” (Graeber, 2001). However, what architects call a good design may not necessarily be ethical design when we consider the cost to our planet. Labelling a product with its carbon emissions brings the societal value of a healthy environment to the same level of awareness in the minds of consumers as the economic value of that product. Carbon emission is still a very intangible concept: it is not easily seen and therefore, can be easily ignored. The motivation for labelling products with their carbon emissions is rooted in a desire to imagine a more complete and immediate assessment of things’ individual and collective value. An individual should be able to see the monetary cost of an object they are purchasing and the collective environmental cost of making that object. Labelling is a tool for designers, but ultimately provides accessible information to an end user. This chapter outlines both the methods and the reasoning behind a carbon counting design project.

Project Aim and Scope

This research starts by choosing metrics to assess sustainable design, followed by a series of designs that make assumptions that appeal to the selected metrics. The furniture designs are then constructed, and a label of metrics is filled out. While documenting the fabrication process, data is collected to evaluate the product's carbon emissions. Future iterations of the design can then be improved based on the results of the initial prototypes. Specifically, four experimental furniture pieces are built as test subjects to evaluate and quantify the environmental impact of design decisions. By applying quantitative values to a product, designers can create iterations of their work based on objective evidence. Carbon labelling has the potential to empower consumers to compare the longevity and environmental impact of a purchase. Modelled after nutrition fact labels, a standard metric for illustrating carbon emissions looks to integrate production transparency into the design industry. The document aims to inform the public about the life cycle of products and provide the information needed by consumers to invest in durable, maintainable, and adaptable designs.

This work is conducted at the scale of an individual researcher, designer, and maker. Some of the lessons learned from this design experiment are intended to be scalable and applicable to the larger field. The scope is limited to furniture design, given its versatile scale and global use. It is challenging to assign non-economic value to a designed object since different individuals and cultures have a range of societal values. Sentimental value isn't quantifiable. For this reason, the system is focused on the measurable aspects of sustainability, specifically a carbon emissions footprint and scorable factors that contribute to longevity (such as the number of adaptable uses of the design). An assumption is made that the quality and longevity of a design increases its chances of becoming sentimental or culturally significant.

Why Count Carbon?

Counting carbon is comparable to counting calories; it can give a rough approximation of the impact individual nutritional decisions have on a system's health. If a person is eating the correct number of calories, one can assume that they are getting the energy they need to function correctly. There are many other factors to health, such as the quality of those calories (described in vitamins, fats, and carbohydrates) and factors outside of diet, like exercise, mental well-being, and environmental conditions. Still, we have made a system to at least track and identify calories and their impact on our health. Nutrition labels call out quantities of calories, fats, sugars, vitamins, and minerals; this helps consumers picture their bodies' needs concerning recommended daily amounts. Since being introduced to American markets in 1994, nutrition labels have become a widely understood and regulated practice (Shapiro, 1995). In stark contrast, we have little to no easily accessible information about carbon emissions in our day-to-day lives.

As with the health of the body, the health of the planet is fundamental for human survival. One indication of the planet's health is the state of its natural carbon cycle. Carbon is found in all living things; it is the essential building block of life. Carbon is naturally emitted and sequestered through processes of growth and decay. The carbon system on Earth consists of complex relationships between the atmosphere, the geosphere, the hydrosphere, and the biosphere. Over millennia, the release and storage of carbon between the four spheres have been miraculously balanced to support life (Heimann, 1993). The Anthropocene epoch (~1950-present) has been marked by human reengineering of this balance, as the burning of fossil fuels has rapidly released carbon stored in the ground into the atmosphere, with one significant consequence being climate change (IPCC, 2021). As people have become more aware of our impact on the planet, they are keen to make changes, but when we collectively have no easy way of associating a quantity to our actions, it is difficult to discern good from bad carbon decisions. We are within our means to attribute a number to an item's carbon emission, even if the method to do so is still debated. Though this data would not look favourably on the actions of some companies, and therefore the widespread dissemination of this information would likely be resisted, this thesis argues that we need greater accountability for the way in which we use the Earth's finite number of resources. Specifically, through the lens of architecture, there are considerable opportunities to reduce emissions in the practice of building. However, without a measurement system, the industry will constantly be debating what constitutes "green" design. So why count carbon? Because it is nearly impossible to change our behaviour if we cannot visualise our contribution to the problem.

Why Build Furniture?

The environmental assessment of buildings is a complex task that looks to grapple with the even more intractable problem of climate change. Currently, architects rely on a patchwork of Life Cycle Assessment (LCA) tools or rating systems such as LEED (Dall'O', 2013). Both LCA tools and rating systems were developed in the 1990s; however, rating systems quickly became the more popular evaluation method (Bernardi et al. 2017, 1226) due to their ease of use. The six most popular tools for environmental building assessment in the world are all types of rating systems (Bernardi et al., 2017). They include:

- LEED (Leadership in Energy and Environmental Design)
- BREEAM (Building Research Establishment Environmental Assessment Methodology)
- CASEBEE (Comprehensive Assessment System for Built Environment Efficiency)
- SBTool (Sustainable Building Tool)
- HEQ (Haute Qualité Environnementale / High Environmental Quality)
- DGNB (Deutsche Gesellschaft Für Nachhaltiges Bauen / German Society For Sustainable Building)

While these systems have laid essential groundwork for taking social accountability for the impact that design decisions have and communicating them to the public, they inadequately describe the entire lifespan of a design. They either focus too heavily on a single aspect (such as energy usage) or look too broadly at a building (as in points systems that abstract and equate unequal design decisions).

Life Cycle Analysis (LCA) attempts to surmount the problems associated with rating systems by more accurately depicting energy use. Therefore, LCA is the technique that aligns most closely with the goals of this project. LCA is defined as "a cradle-to-grave or cradle-to-cradle analysis technique to assess environmental impacts associated with all the stages of a product's life, from raw material extraction through materials processing, manufacture, distribution, and use." (Muralikrishna & Manickam, 2017). Calculating the carbon emissions for the entire life cycle of a building would be an accurate way to analyse a project with a broad scope with a high level of detail. However, calculating the life cycle emissions of every bolt and beam used in construction is a daunting task. Many industry experts agree the quality and availability of data are not yet ready to mandate building Life Cycle Assessments (LCAs) or Environmental Product Declarations (EPDs) (Frischknecht et al., 2019).

An emissions analysis could involve breaking a project down into small manageable components. If the building industry were to share the responsibility of calculating the emissions of individual materials and components, architects and engineers would only need to sum up those parts. Totalling carbon is a task that Building Information Modeling (BIM) could easily incorporate, contributing to a numeric understanding of embodied carbon in early design phases. Emissions from operational energy would have to be monitored after construction and would reflect the efficiency of the building enclosure.

So, why furniture? Furniture provides this design project with a manageable scale to take a deep dive into identifying aspects of a carbon-intensive project. The embodied energy of a building's furnishing makes up a significant component of the building's embodied emissions. Furniture building provides the opportunity to create something, investigates craft through making, and holds this research accountable to the challenges and realities of bringing a concept to fruition.

Architecture, Product Design, & the Food Industry

When it comes to disclosing a product's contents, the design industry falls behind the food industry in its degree of communication. Just as people deserve to know what ingredients make up their food, people have the right to know what goes into their belongings. CO2 visualization, as explained in the book *Carbon Footprint of Products*, is a crucial move in developing an awareness of one's impact on what is otherwise an invisible emission.

> "To realize sustainable consumption, it is important to show the consumers the [Green House Gasses] of the consumer's behaviour or action, which is called "CO2 visualization." The [Carbon Footprint of a Product] is one of the tools of the "CO2 visualization" (Inaba et al., 2016)

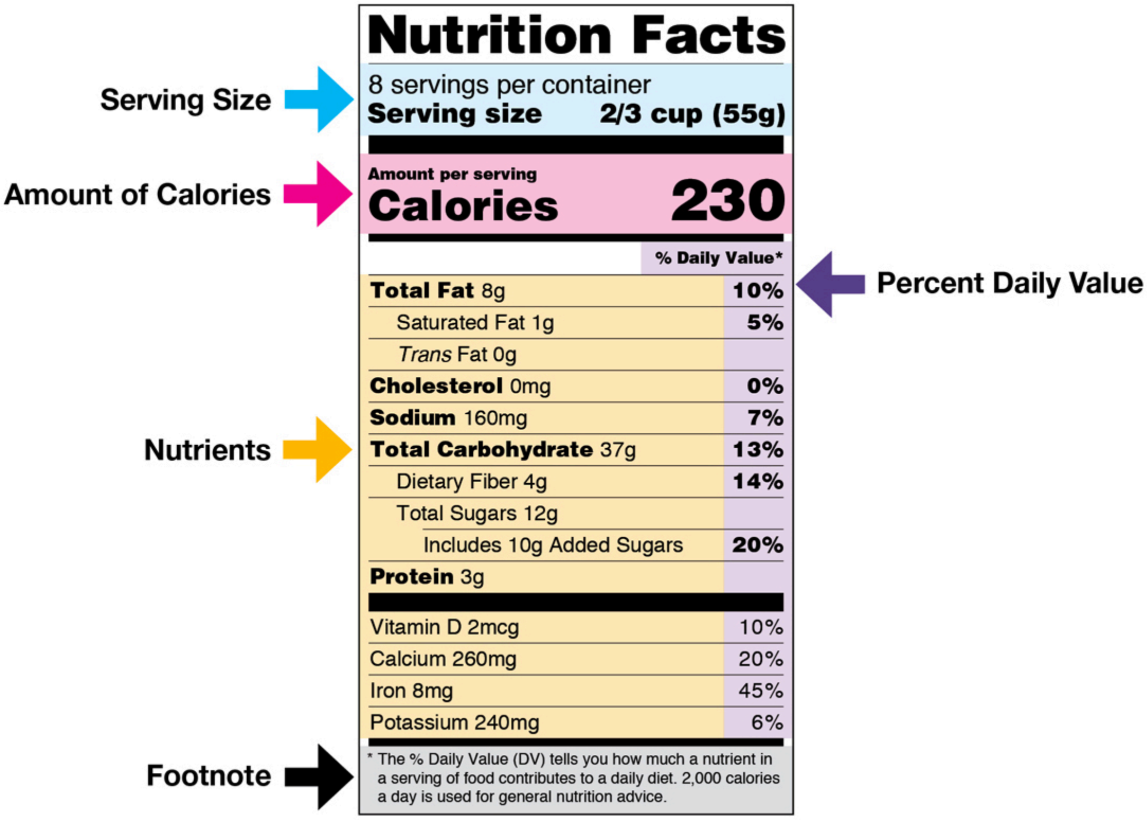
Calculating the embodied carbon of a building is a far more complex task than assessing the carbon embodied in something like an apple. However, if there was a precedent for labelling smaller scale products, it becomes much easier to imagine evaluating projects at the scale of architecture. For example, if the manufacturers of windows and doors sold their products with a carbon label, this data could easily be included in Building Information Modelling (BIM) software and an accurate embodied carbon tally could be shown as a building is designed. Projects could have both a monetary budget and a carbon budget.

The introduction of Life Cycle Assessment (LCA) standards from the International Organization for Standardization into architecture has been considered: “The proposition of using cradle-to-grave in ISO 14067 will promote the use of Building Information Modeling (BIM) or other simulation technologies to identify the [Green House Gas] emissions of the materials/products in their true life cycle” (Wu et al., 2015). If the world has a system (BIM) to evaluate the cost of a building and its thousands of components, one can imagine the creation of a similar system to account for carbon. Designers would have the ability to make informed decisions at multiple stages of a project. For example, various cladding systems could state their carbon/area, instantly communicating to those making design decisions what elevation option has higher embodied carbon emissions. Instead of tackling the problem at a large scale (using points/holistic rating systems), the problem could be broken down and distributed across industries, where every manufacturer calculates the carbon of their portion of the project under the same regulations.

The food industry has already experimented with carbon labelling on food products. The systematisation of nutrition facts has laid the groundwork for introducing carbon labelling to food products. Since 2008, the UK company Carbon Trust has worked with the grocery chain Tesco to label food products with their carbon footprint. Similar strategies have since been implemented at various scales in France by the company Casino, in Japan under the Japan Environmental Association for Industry (JEMAI), in Korea under the Korea Environmental Industry & Technology Institute (KEITI), and in Thailand under the Thailand Greenhouse Gas Management Organization (TGO) (Inaba et al., 2016).

The American legislation that created the *Nutrition Facts* label in 1990 includes a comprehensive database and estimates standardised percentages based on an average person’s diet (Shapiro, 1995). These government databases are easily accessed in North America from *The Canadian Nutrient File* and the USDA’s *FoodData Central* (Government of Canada) (USDA). Governments could provide similar easily accessible databases for a person’s average carbon emissions. If the process for the Life Cycle Assessment (LCA) of

Figure.1 *Carbon Trust Label*



Nutrition Facts

8 servings per container
Serving size 2/3 cup (55g)

Amount per serving
Calories 230

	% Daily Value*
Total Fat 8g	**10%**
Saturated Fat 1g	**5%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 160mg	**7%**
Total Carbohydrate 37g	**13%**
Dietary Fiber 4g	**14%**
Total Sugars 12g	
Includes 10g Added Sugars	**20%**
Protein 3g	
Vitamin D 2mcg	10%
Calcium 260mg	20%
Iron 8mg	45%
Potassium 240mg	6%

* The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

(For educational purposes only. These labels do not meet the labeling requirements described in 21 CFR 101.9.)

Figure.2 *Nutrition Facts Label*

products (and perhaps one day buildings) was simplified at the cost of some accuracy, the overall benefit might still be greater. An increase in products that have a general estimate of their carbon footprint has the potential to be more impactful than a few products that were subjected to rigorous analysis. This process will be tested and analysed in this thesis through the construction of furniture pieces.

The planet is a highly complex system that is self-regulating and in balance when recent anthropogenic factors are removed from the equation. The relationship between embodied and operational carbon is contested in literature. Operational energy use can greatly vary depending on the climate, energy use habits, and building performance (Ibn-Mohammed et al., 2013). Depending on these factors, one can make embodied carbon as insignificant as 3% or as significant as 80% of a building's life cycle emissions (Ibn-Mohammed et al., 2013). When assessing a building's carbon footprint, there is a tendency to give more attention to operation energy, but because of recent improvements to building performance, embodied energy is becoming more significant: "global efforts to reduce emissions in buildings can-not be totally achieved by ignoring the emissions embodied in buildings" (Ibn-Mohammed et al., 2013) While the operational energy of existing buildings (over their lifespan) generally outweighs the embodied carbon of their materials and construction processes, new buildings constructed with net-zero energy goals will need to place greater emphasis on their embodied carbon (Giordano et al., 2017); this would shift the focus of future design to the impacts of material selection and production processes. As building envelopes become more efficient, it is increasingly important to consider what goes inside a building. Furniture and appliances contribute 10 and 25 per cent of a building>s embodied carbon, respectively (Hoxha & Jusselme, 2017).

Both carbon labels and building rating systems continue to be developed in various countries. Carbon labels are an example of a Life Cycle Assessment (LCA) tool that accounts for all carbon emissions at all stages of a product's lifespan. Popular building rating systems, such as LEED and BREEAM, use a points system to assign a score to a building. Rating systems have grown in popularity as they have been easier to implement because they are primarily task-based rather than data-based (Bernardi et al., 2017). Nigel Howard has been influential in developing multiple green rating systems; he was a creator of BREEAM98 and Vice President of the US Green Building Council, where he helped develop LEED. In a paper interviewing Howard, it was noted that:

> “any rating system itself needs to be limited to a few key issues that are easy and cost-effective to assess, as well as having a clear value proposition to the building owner and tenants who often have different concerns and interests. Howard feels that no rating system has got it right yet, except where it is mandated by governments.” (Ade & Rehm, 2020)

It is critical to continue researching alternative labelling systems. It is evident that the success of rating systems is scattered across multiple industries, and a consistent way to evaluate environmental impacts arguably does not exist. Whether disclosing carbon in food, products, or architecture, clear communication and a universally accepted evaluation system are needed to identify unsustainable behaviours and promote ethical design through awareness.

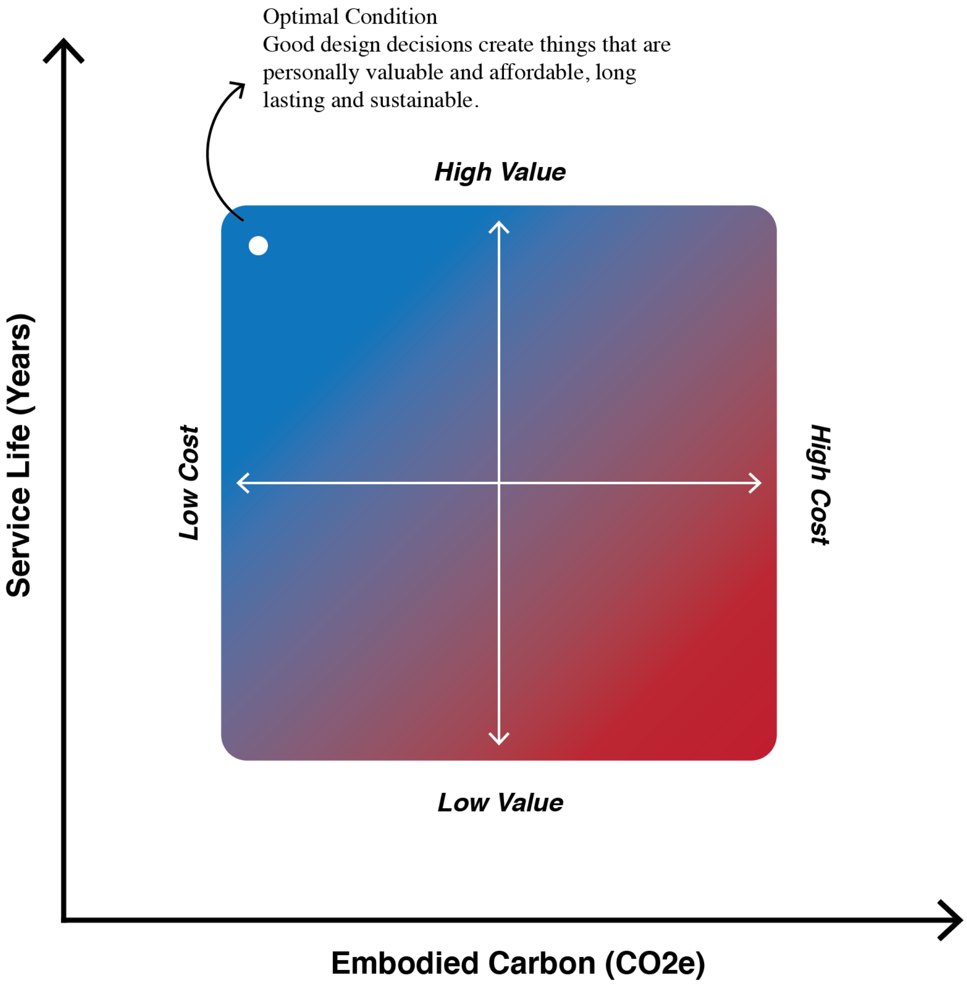
Context

Manifesto: The Good Design Matrix

There are numerous problems to be solved when one looks at the average lifestyles of those in industrialised high-income countries, but arguably the most pressing and interrelated concerns are mass overconsumption and environmental degradation. John Elkington, an authority on corporate responsibility and sustainable capitalism, business author, and adviser, describes the “triple bottom line” for sustainable business as the combination of economy, society, and environment (Elkington, 1998). There is no society without the environment, and there is no economy without a society. Therefore, there is an intrinsic hierarchy to the system we have created, and it needs to put the environment first to develop a healthy symbiosis with the land that sustains human development. The Intergovernmental Panel on Climate Change (IPCC) is certain that industrialisation and the subsequent years of continuous production of goods and services are responsible for the planet's change in climate: "Observed increases in well-mixed greenhouse gas (GHG) concentrations since around 1750 are unequivocally caused by human activities" (IPCC, 2021).

What's more, studies have shown that after a period of growth and its resulting pollution, countries that experience economic development legislate more stringent environmental policies: "As nations or regions experience greater prosperity, their citizens demand that more attention be paid to the non-economic aspects of their living conditions" (Grossman & Krueger, 1995). It is a complex problem with no single solution, but since returning to a pre-industrialised society or continuing with *business as usual* are not possible options, sustained, maintainable growth may be the only way forward. That is the goal of the nearly overused word "sustainability", defined in the Brundtland Report as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). By this account, a step towards true sustainability in design industries would involve the creation of a system based on international standards to communicate the embodied carbon and estimate the longevity of a product or building to consumers. By requiring a life cycle assessment label on products, designers and producers are incentivised to make decisions that decrease carbon emissions while also increasing the lifespan of products.

Created for this thesis, the *Matrix for Good Design* will aid in making decisions during the design process. The matrix has four major



Optimal Condition
Good design decisions create things that are personally valuable and affordable, long lasting and sustainable.

Illustration.2 *The Good Design Matrix, Graphic by Author* variables: service life span, embodied carbon, value, and cost. Service life and embodied carbon are design metrics that serve the common good—things that most of society sees as mutually beneficial. Good design should be capable of lasting beyond a single user or occupant, objectively valuable for future generations, and reduce the need to extract more resources. Climate change is estimated by the World Health Organisation (WHO) to cause 250 000 additional deaths per year between 2030 and 2050, all caused by increased heat waves, natural disasters, flooding, and infectious diseases (World Health Organization, 2014). Investing in low carbon emission designs is in the best interest of communities worldwide as we are faced with increased preventable deaths.

Cost and value are decisions that relate to the individual. Value is a broad term that is intentionally used as it is subjective to individuals and cultures. Design that adds value to the life of the user is good design. If the design can add value at both an affordable price to the consumer and a low cost to the producer, it is likely to be a successful design. This matrix places the best possible design at the intersection of low cost and low carbon, high value and high service life. Overall, the Matrix for Good Design is intended to reward a design that benefits both the individual user and the larger global community.

On Making & Craft

Wood is an extraordinary material. Its versatile and workable nature allows for finely tuned adjustments to be made to any piece. Many components in this project were made by the patient, slow process of sanding rough objects into their desired shapes. While there are machines capable of creating some of these pieces, there is a fantastic connection between maker and material that only occurs when a shape is perfected by a hand. Handcraft is a slow and intentional process—one that our industrialised, fast-paced world rarely tolerates. The making process would need to be optimized to allow for larger-scale production of sustainable design, as environmental products should be accessible to the average consumer as a piece for utility and not merely relegated to the realm of expensive artworks, reserved only for those who can afford them.

The initial investment of time makes the object much more valuable to the maker. Seeing the effort that goes into making something changes one's perception of that item, and the added time spent begets care and appreciation for the object. Slow handcraft is at odds with our modern relationship to consumption, where a few clicks on a screen can bring an object to your door. We do not see who made it, where it was made, from what it was made, or how long it took to make it. Our loss of connection to the act of making and the origins of our everyday objects greatly desensitises us; it is what enables us to live in a throwaway culture. Here, companies are rewarded financially for designing things intended to break—why sell a person one item at x cost when you can sell them three at half the original cost? The illusion of getting a good deal on something that will be more expensive in the long term creates a pattern of disposable consumption that will lead to the death of craft. Richard Sennett, a professor of Sociology and Humanities, discusses the current disconnect between the designer and the maker, stating that "the head and the hand are not simply separated intellectually but socially" (Sennett, 2008). The process of making things by oneself is one way to reconnect with the value of craft.

Designing a product intended to fail is known as planned obsolescence; it is commonly practised in many industries (Satyro et al., 2018). The mass consumption of resources and goods is a societal mentality that gained traction in the post-war period, described by 20th century economist Victor Lebow in his article entitled *Price Competition in 1955.*

> "Our enormously productive economy demands that we make consumption our way of life, that we convert the buying and use of goods into rituals, that we seek our spiritual satisfac-

> tions, our ego satisfactions, in consumption. The measure of social status, of social acceptance, of prestige, is now to be found in our consumptive patterns” (Lebow, 1955)

This thinking has persisted into the 21st century and likely will continue if not changed through intense social, political, and economic pressures. Our consumption habits are designed for us as much as our buildings and belongings are. The problem of excess waste can be surmounted if the world can relearn the value of everyday things.

State of the Art

Three primary precedents are studied to create this project: examples of process-driven furniture design, labels/rating systems, and documents on sustainable development. Within 20th century Western furniture design, Alvar Aalto, the Eames’, and Hans Wegner provide inspirational work related to prototyping, scalable learning, and designing with a process in mind. Aalto refined and patented a process for wood bending that he first explored in relief art, then incorporated into furniture, and finally influenced his architectural designs. Using birch wood locally available in Finland, Aalto engaged in material explorations that displayed innovative applications of bent wood (Ando & Fleming, 2019) The Eames’ famously experimented with plywood moulds, making the tools and the original batch of their now-famous chairs themselves. They experimented with wood lamination in their apartment, engaging in a process that heavily relied on prototypes and the natural forms of the body. Aesthetics were still a concern, but the larger process took precedence: the production of durable and comfortable chairs (Eames et al., 2015). Furniture designer Hans Wegner exhibited an admirable determination to iterate. Designing over five-hundred chairs in his lifetime, he has been quoted saying, “if only you could design just one good chair in your life...But you simply cannot”. Wegner cared deeply for craftsmanship, taking inspiration from traditional tools such as axes and oars (Olesen Christian, 2014). The conscious selection and wielding of materials exhibited by Hans Wegner is an aspirational example for creating the furniture pieces produced for this research.

1920

1929-33

Alvar Aalto

Wood bending experiments, local birch wood. Process driven design.

1944

Emco

*"Make more with less.
In 1944, it was recycled aluminum.
Today, there's a lot more to reclaim."*

1984-Pre

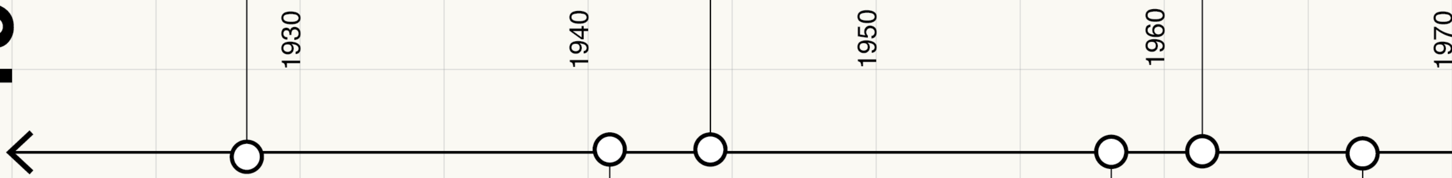
Benchma

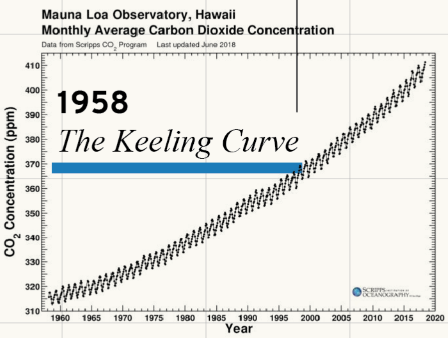
*'I have alwa
production,
one-off piec*

*OVO (2018) - W
Foster + Partne*

1962

Rachel Carson, Silent Spring





1958

The Keeling Curve

1941-45

Eames

Molded plywood experiments

1967

Tacchini

*"Like in an agricultural supply c
– is it possible therefore to have a
zero miles approach in the design
industry too?"*

esent
rk

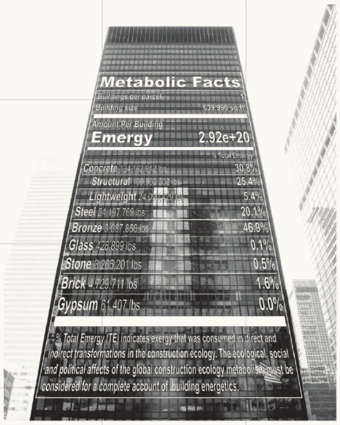
ys liked the process of
rather than making
es'

Vith
ers

Sage (2019)- With David Rockwell

2006
Mater
Circular Furniture Design

2020
Kiel Moe
Analysis of the Segram building

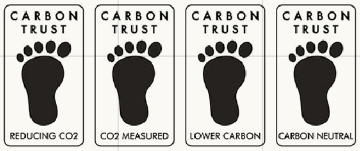


Metabolic Facts

Buildings per parcel	1
Building size	639,990 sq.ft.
Amount Per Building	
Emergy	2.92e+20
	% Total Emergy*
Concrete 134,162,912 lbs	30.8%
Structural 109,982,202 lbs	25.4%
Lightweight 24,090,429 lbs	5.4%
Steel 24,197,769 lbs	20.1%
Bronze 3,087,868 lbs	46.9%
Glass 428,899 lbs	0.1%
Stone 3,265,201 lbs	0.5%
Brick 4,729,711 lbs	1.6%
Gypsum 61,407 lbs	0.0%

* % Total Emergy (TE) indicates exergy that was consumed in direct and indirect transformations in the construction ecology. The ecological, social and political affects of the global construction ecology metabolism must be considered for a complete account of building energetics.

2001
Carbon Trust



1996
ISO 14000 Series
Enviromental Managmemt

1981
The Brundtland Report

1980

1990

2000

2010

2020

976
The First World Conference
On the Environment

1989
IPCC

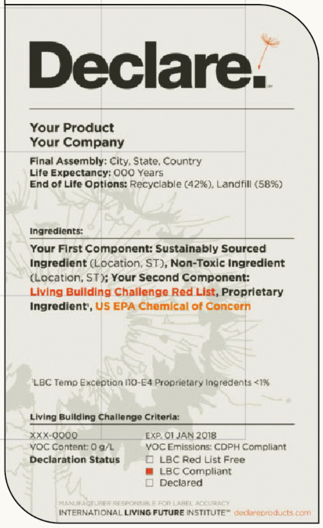
1990
BREAM

1998
LEED

2005
From Us With Love

"Form Us With Love likes finding problems in the ways things are made, consumed, used, and discarded"

2012
Declare Label



Declare.

Your Product
Your Company

Final Assembly: City, State, Country
Life Expectancy: 000 Years
End of Life Options: Recyclable (42%), Landfill (58%)

Ingredients:

Your First Component: Sustainably Sourced Ingredient (Location, ST), **Non-Toxic Ingredient** (Location, ST)**; Your Second Component: Living Building Challenge Red List, Proprietary Ingredient**[1], **US EPA Chemical of Concern**

[1] LBC Temp Exception I10-E4 Proprietary Ingredients <1%

Living Building Challenge Criteria:

XXX-0000	EXP. 01 JAN 2018
VOC Content: 0 g/L	VOC Emissions: CDPH Compliant
Declaration Status	☐ LBC Red List Free ■ LBC Compliant ☐ Declared

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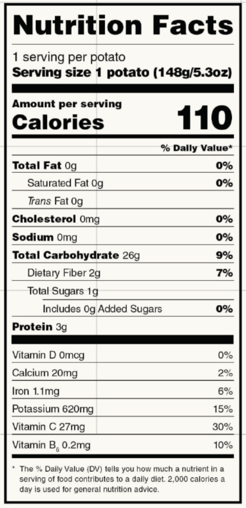
hain
a
n



Nutrition Facts

1 serving per potato
Serving size 1 potato (148g/5.3oz)

Amount per serving **Calories**	**110**
	% Daily Value*
Total Fat 0g	**0%**
Saturated Fat 0g	**0%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 0mg	**0%**
Total Carbohydrate 26g	**9%**
Dietary Fiber 2g	**7%**
Total Sugars 1g	
Includes 0g Added Sugars	**0%**
Protein 3g	
Vitamin D 0mcg	0%
Calcium 20mg	2%
Iron 1.1mg	6%
Potassium 620mg	15%
Vitamin C 27mg	30%
Vitamin B_6 0.2mg	10%

* The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

Declare.

Your Product
Your Company

Final Assembly: City, State, Country
Life Expectancy: 000 Years
End of Life Options: Recyclable (42%), Landfill (58%)

Ingredients:

Your First Component: Sustainably Sourced Ingredient (Location, ST), **Non-Toxic Ingredient** (Location, ST); **Your Second Component: Living Building Challenge Red List, Proprietary Ingredient**[1], **US EPA Chemical of Concern**

[1]LBC Temp Exception I10-E4 Proprietary Ingredients <1%

Living Building Challenge Criteria:

XXX-0000
VOC Content: 0 g/L
Declaration Status

EXP. 01 JAN 2018
VOC Emissions: CDPH Compliant
☐ LBC Red List Free
■ LBC Compliant
☐ Declared

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Figure.3 *The Declare Label, From the International Living Future Institute*

Benchmark Furniture, founded in 1984, develops pieces that prioritise craftsmanship and sustainability. They have partnered with architects, such as Foster + Partners and David Rockwell, to create functional and well-crafted furniture. Benchmark boasts a range of awards and certifications, but most notably the *Declare Label* is one example of their commitment to communicating the life span and material ingredients of their designs. The *Declare Label* is an initiative put forward by the International Living Future Institute as a part of its mission to be "a transparency platform and product database that is changing the materials marketplace"
(Living Future, 2021). Declare is compatible with programs such as the Living Building Challenge and LEED. The label lists ingredients, product life expectancy, end-of-life options, a checkbox for Red List Free (toxic materials), and an optional field for embodied carbon (Living Future, 2021). The Declare Label aligns closely with this research, differing in that this project focuses heavily on carbon emissions, adaptability, and how labelling affects design. Furniture Manufacture Herman Miller was an early adaptor of Cradle-to-Cradle principals and use an internal label to assess and keep track of materials they frequently use (Lee & Bony, 2007). Internal labelling systems create points of documentation that can be referenced in future projects.

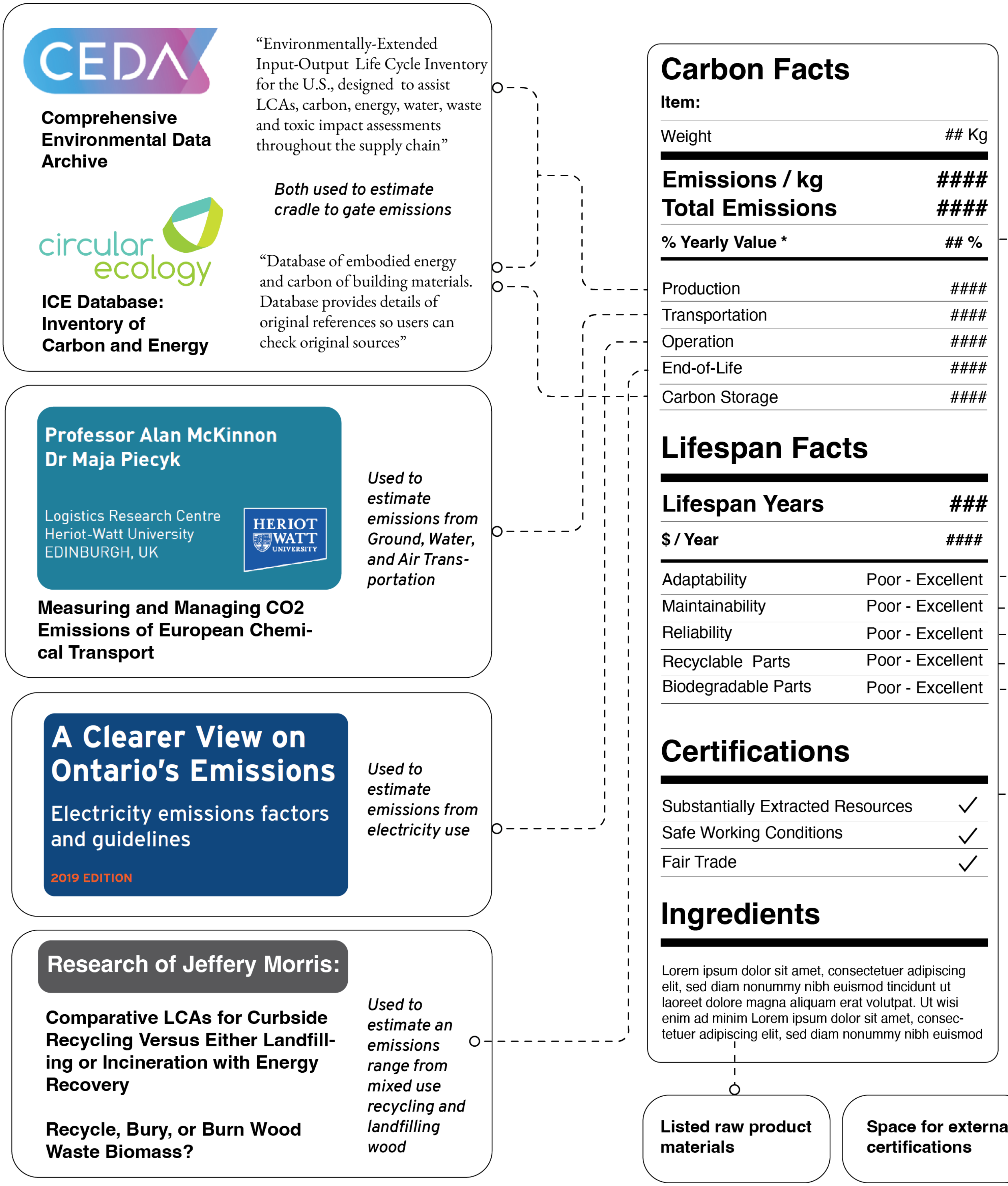
The numerous green building rating systems should also be mentioned here. Programs such as LEED, BREEAM, CASEBE, DGNB, HEQ, and SBtool were identified and compared in the paper *An Analysis of the most Adopted Rating Systems for Assessing the Environmental Impact of Buildings.* The authors found that not all systems analysed the whole life cycle of a building and that the primarily qualitative ratings still need to be represented based on sound evidence (Bernardi et al., 2017). Some aspects of these systems have been applied to this thesis, focusing on incorporating quantitative carbon data, integrating the system into the early design process, and communicating the results.

Methods

A two-part approach is proposed to address the communication of good design. First, a metric for evaluation is created, followed by a series of experiments to explore and determine the success of the metric. This research aims to highlight unsustainable practices in a design process by creating a label with multiple criteria to communicate in a standardised way the quality and environmental impact of a product. These metrics are factors based on the *Good Design Matrix* and an overview of stages in a Life Cycle Assessment (LCA).

To test the metric, four experiments are conducted through the design and construction of a lamp, a desk, a bed, and a chair. They are designed with the evaluation criteria of the label in mind, aiming to have a desirable score in each category. A successful design has a high score (described on a scale from poor to excellent) in adaptability, maintainability, and durability, while maintaining a low numeric value for carbon emissions per kilogram. These experiments have determined that, under present circumstances, an item that emits one kilogram of carbon per kilogram of final mass would be an efficient design, though carbon neutral or carbon negative results should be the goal. The building process is documented with enough detail that it is possible to make an accurate assessment of each category on the label. Documentation involves recording the inputs and outputs of individual fabrication processes. Examples of the recorded data include cost, weight, waste, distance travelled, and the amount of energy used (fuel or electricity). Green House Gas (GHG) emissions can be estimated from this information. The more qualitative aspects of the design, such as adaptable positions of each piece, can be assessed through both drawings and final photographs.

Label Breakdown



Comprehensive Environmental Data Archive

"Environmentally-Extended Input-Output Life Cycle Inventory for the U.S., designed to assist LCAs, carbon, energy, water, waste and toxic impact assessments throughout the supply chain"

Both used to estimate cradle to gate emissions

ICE Database: Inventory of Carbon and Energy

"Database of embodied energy and carbon of building materials. Database provides details of original references so users can check original sources"

Professor Alan McKinnon
Dr Maja Piecyk

Logistics Research Centre
Heriot-Watt University
EDINBURGH, UK

Measuring and Managing CO2 Emissions of European Chemical Transport

Used to estimate emissions from Ground, Water, and Air Transportation

A Clearer View on Ontario's Emissions

Electricity emissions factors and guidelines

2019 EDITION

Used to estimate emissions from electricity use

Research of Jeffery Morris:

Comparative LCAs for Curbside Recycling Versus Either Landfilling or Incineration with Energy Recovery

Recycle, Bury, or Burn Wood Waste Biomass?

Used to estimate an emissions range from mixed use recycling and landfilling wood

Carbon Facts

Item:

Weight	## Kg
Emissions / kg	**####**
Total Emissions	**####**
% Yearly Value *	**## %**
Production	####
Transportation	####
Operation	####
End-of-Life	####
Carbon Storage	####

Lifespan Facts

Lifespan Years	**###**
$ / Year	**####**
Adaptability	Poor - Excellent
Maintainability	Poor - Excellent
Reliability	Poor - Excellent
Recyclable Parts	Poor - Excellent
Biodegradable Parts	Poor - Excellent

Certifications

Substantially Extracted Resources	✓
Safe Working Conditions	✓
Fair Trade	✓

Ingredients

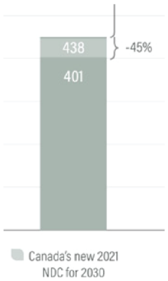
Lorem ipsum dolor sit amet, consectetuer adipiscing elit, sed diam nonummy nibh euismod tincidunt ut laoreet dolore magna aliquam erat volutpat. Ut wisi enim ad minim Lorem ipsum dolor sit amet, consectetuer adipiscing elit, sed diam nonummy nibh euismod

Listed raw product materials

Space for externa certifications

CANADA'S CLIMATE ACTIONS

FOR A HEALTHY ENVIRONMENT AND A HEALTHY ECONOMY



2021 Nationally Determined Contribution - 438 Mt to 401 Mt

To help visulise carbon, the lable takes the 2030 emissions goal of the selected country (Canada) and divides it by the population to give a yearly value to each citizen. The total emissions of the product is divided by the yearly emission to give an idea of the percentage that a product is contributing to a person's carbon footprint.

	Excelent		Very Good		Good		Better		Poor	
	10	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Adaptability	5+ Adaptable Uses		4 Adapatble uses		3 Adaptable Uses		2 Adaptable Uses		1 Adaptable Use	
Maintainability	90-100 % Replacable Parts	80-90 % Replacable Parts	70-80% Replacable Parts	60-70 % Replacable Parts	50-60 % Replacable Parts	40-50 % Replacable Parts	30-40 % Replacable Parts	20-30 % Replacable Parts	10-20 % Replacable Parts	0-10 % Replacable Parts
Reliability	>5x Stardard Stresses	5.0x Stardard Stresses	4.5x Stardard Stresses	4.0x Stardard Stresses	3.5x Stardard Stresses	3.0x Stardard Stresses	2.5x Stardard Stresses	2.0x Stardard Stresses	1.5x Stardard Stresses	1.0x Stardard Stresses
Recyclability	90-100 % Recyclable Parts	80-90 % Recyclable Parts	70-80% Recyclable Parts	60-70 % Recyclable Parts	50-60 % Recyclable Parts	40-50 % Recyclable Parts	30-40 % Recyclable Parts	20-30 % Recyclable Parts	10-20 % Recyclable Parts	0-10 % Recyclable Parts
Compostability	90-100 % Compostable Parts	80-90 % replacable parts	70-80% replacable parts	60-70 % replacable parts	50-60 % replacable parts	40-50 % replacable parts	30-40 % replacable parts	20-30 % replacable parts	10-20 % replacable parts	0-10 % replacable parts

Managing Complex Systems, Howard Eisner

"A robust system is one that continues to operate under various kinds of stress, although it may be forced to do so in a degraded mode. It is a "slow-die" system that has relatively few single-point failures that are catastrophic. Such a system has been designed with special consideration given to reliability, maintainability, and availability (RMA) actors, as well as the required logistics support to assure appropriate RMA levels"(Eisner, 2005, p.154)

RMA is applied to the lable in very broad sense. The principals of Reliability, Maintainability, and Availability (changed to Adaptability on the lable) allow systems engineers to design lasting and robust systems. The hope is that RMA principals encourage designs that have multiple uses, that offer replaceable parts, and that are built beyond basic requirements for durability.

The Prototyping Process

A cohesive set of materials is used for the design of all four furniture prototypes. To learn and create points of comparison within a standardised label, the sourcing, processing, and fabrication methods are permitted to change between prototypes. The construction process is iterative; mistakes made in the first furniture prototype are adjusted in the second to fourth. Simultaneously, the metric can be updated to account for what was learned from the making process. To reduce joining methods, such as glues and metal fasteners, the process of wood steam bending is proposed. This process is tested and evaluated through prototypes to test its efficiency and success in carrying out the designs. This process develops a design language that is a visual cue for sustainable design.

Designing the Evaluation System

For quantifying carbon emissions at different stages of an item's life cycle, International Organization for Standardization (ISO) statutes ISO 14067 and ISO 14044 are referenced. "The ISO 14060 family provides clarity and consistency for quantifying, monitoring, reporting and validating or verifying GHG emissions and removals to support sustainable development" (International Organization for Standardization, 2018) The ISO also outlines detailed requirements to produce a Carbon Footprint of a Product (CFP) Report. The resulting label created for this project is influenced by ISO documents and displays the total emissions for each prototype at each life cycle stage.

The evaluation criteria for service life are rooted in systems engineering. When designing robust systems or products, one can look to the principles spelled out by the acronym RMA—reliable, maintainable and available—to create something that can perform consistently, can be easily repaired, and can operate in an "up-state" for an extended time (Eisner, 2005). These factors contribute to the lifespan of systems and can be applied to everyday products. For the purposes of the products produced in this thesis, availability is changed on the label to *Adaptability*, following the logic that the more adaptable uses a design has, the more available for use it will be. For example, a chair that functions as both a lounge chair and a dining chair is useful to a user in twice as many circumstances compared to a chair that serves one function. On the label, reliability, maintainability, and adaptability factors are scored on a scale from poor to excellent. If a manufacturer offers the replacement of ninety per cent of a chair's components, it receives an "excellent" (or 9/10) for maintainability. The scoring system aims to encourage modular and repairable design by rewarding the RMA tenets, while also rewarding traditional sustainability strategies, such as design options using a percentage of truly recyclable or biodegradable content.

Creating the Label

The following is an explanation of each section included on the *Carbon Facts Label*:

Production:

This value includes cradle-to-gate emissions and final manufacturing emissions. Cradle-to-gate refers to the sum of carbon emitted when extracting, transporting, and processing raw resources. Manufacturing emissions for this project include the electricity used while operating power tools. Manufacturing emissions are calculated based on hours of tool use.

The CEDA database is used for cradle-to-gate values (Suh, 2010). The Atmospheric Fund's document, *A Clearer View on Ontario's Emissions: Electricity emissions factors and guidelines,* is used to calculate electrical emissions from tool use (Sotes, 2019).

Transportation:

Transportation is a sum of the emissions released when moving materials or products from the gate (factory) to the final assembly site (workshop). This often involves shipping from a factory to a point-of-sale and then to the workshop. Research by Professor Alan McKinnon and Dr Maja Piecyk is used for transportation emissions (McKinnon & Piecyk, 2011)

Operation:

Operational emissions are displayed in a per year value. The carbon is estimated from electricity use on the power grid in Ontario, Canada. This value should change depending on the region where the label is being printed. Operational energy is an important category, but in the context of furniture it only applies to the lamp.
The Atmospheric Fund's document, *A Clearer View on Ontario's Emissions: Electricity emissions factors and guidelines,* is referenced for electrical emissions (Sotes, 2019).

End-of-life:

EoL is the most uncertain category because it is tasked with estimating future emissions. The label assumes that fifty per cent of the product is recycled and fifty per cent is landfilled. The final value assumes 250km of truck transportation to a recycling facility and 50km to a landfill. The calculation uses an approximate figure for CO2e / kg of mixed recycling (papers, plastics, metals, glass).
For assumptions about the end-of-life emissions from wood and recycling, the research of Jeffery Morris is referenced (Morris, 2017) (Morris, 2005)

> " (Morris, 2005), cardboard, glass containers, aluminum can sheet and plastic pellets with virgin materials emits 3,289 kilograms (kg) of carbon dioxide equivalents, compared with the 842 kgs emitted to manufacture this same quantity and mix of products with the recycled

> materials components that were, on average, in each metric ton of materials collected for recycling from SLO households and businesses during 2002." (Morris, 2005)

For landfilling, a figure for CO2e / kg of wood is used. The figure is specific to wood because that is the primary material of the furniture. Wood also releases significant greenhouse gasses when decomposing. This calculation uses a worst-case scenario; landfills with methane capturing technology could perform significantly better.

> "Assuming landfill gas (LFG) is 50/50 methane and CO2, and ignoring LFG generated after 100 years, landfilled wood has global warming potential (GWP) of 1,152 kg CO2-eqMg−1 wood based on DynCO2 calculated discounts for delayed releases. At landfills capturing 75% of LFG, the 100-year GWP for delayed releases is 288 kgCO2-eq." (Morris, 2017)

This calculation should be refined for products made from different materials than those used in this project and when the disposal methods of products can be guaranteed.

Carbon Storage:

Carbon storage is included as a separate entry specifically to communicate the CO2e emissions sequestered in a product. This value primarily applies to wood products. This value comes from the Inventory of Carbon and Energy (ICE) database, which includes values for various building materials' carbon storage and emissions. The values for hardwood (-1.59 kgCO2e/kg) and softwood (-1.55 kgCO2e/kg) are used for the furniture.

The ICE database is used in the calculation of all carbon storage values (Jones, 2019)

Adaptability:

This category describes the versatility of the product. Obsolescence has been previously identified as a contributor to waste—adaptability rewards products that have multiple uses that allow these products to work in various situations that would otherwise require the purchase of a new or additional product.

Reliability:

Reliability aims to describe the durability of the product. This category is a way of identifying and rewarding a product that is built to withstand more than the minimum expected force.

Maintainability:

Maintainability promotes modular designs that can be disassembled. This category represents the number of replaceable parts a company offers. When components are easy to replace, an object is more likely to be repaired.

Recyclability and Compatibility:

An assessment of the percentage of components that can be recycled or that are biodegradable

Certifications:

A space is reserved on the label for external companies' certifications. Some imagined categories are Sustainable Extracted Resources, Safe Working Conditions, and Fair Trade business deals. This area is not officially assessed for the furniture created in this project.

Ingredients:

All the raw materials used to make the product are listed at the base of the label.

Data Source Summary

The project relies on third-party data to estimate carbon emissions. Five databases and documents were used in the calculations:

- For hardwood production and carbon storage, the ICE database is used (Jones, 2019)
- For transportation, the research of Professor Alan McKinnon and Dr Maja Piecyk is used (McKinnon & Piecyk, 2011)
- For carbon emissions from the local electrical grid, the Atmospheric Fund's document, *A Clearer View on Ontario's Emissions: Electricity emissions factors and guidelines,* is used (Sotes, 2019)
- For assumptions about the end-of-life emissions from wood and recycling, the research of Jeffery Morris (Morris, 2017) (Morris, 2005) is used
- All remaining parts, including metals and electronics used the CEDA Database (Suh, 2010).

Each one of these databases and documents contain values of CO2e (carbon equivalent emissions) in units such as grams CO2e / kilogram of weight (CO2e/kg), grams CO2e / tonne-kilometer (CO2e /tn-km), and grams CO2e / kilowatt hour (CO2e/kwh)

Mapping Supply Chains

A Geographic Information System (GIS) map of countries, deep-sea shipping routes, and roads illustrates the origins of all product components. For international shipping, the assumed route is traced across shipping lanes. Points are created for every known location from longitude and latitude data—a mapping software plug-in calculates road routes to find the fastest route between selected points.

The shipping route map illustrates the level of certainty for the route and the mode of transportation. A black dot is a known location point of an item, while a red dot is an assumed location(such as a port

Figure.4 *Example of Supply Chain, Map by Author*

between two known locations). Red lines are land routes, blue lines represent water routes, and yellow lines signify flight paths.

The GIS map is an essential tool for tallying transportation distances. Emissions from the transportation of components at various stages of the product's life can be estimated by knowing the weight, distance, and method of transport.

Assumptions

Assumptions about various third-party items' shipping routes and transportation methods were made. Where possible, the exact locations and routes were used. Enquiries were sent to companies about their supply chain, and typically only responses from small to medium-sized businesses were received. Items from large suppliers, such as Home Depot, Amazon, and Digikey, are shrouded in the most significant uncertainty regarding how they get from their various manufacturing gates to the point of sale. If the furniture pieces within this project were being produced commercially, the intermediaries that an individual maker uses could be avoided and the supply chain would be more straightforward.

The small electrical components for the lamp were specifically challenging to find from a local supplier. The wire and DC jacks were produced in the northeastern United States, while parts such as the LED driver, lightbulbs, and switches came from eastern China.

The logic that follows was applied for route assumptions. From China to North America, the distance of three popular shipping routes was averaged: one through the Suez Canal, one through the Panama Canal, and one to a western North American port (avoiding canals). The item is assumed to have arrived at a port in the county it was sold. The item is most likely to arrive at the most prominent international ports: Vancouver, Montreal, or Halifax for Canada; and Los Angeles and New York / New Jersey for the US. The shipping method from China to North America is by container ship. Once in continental North America, road freight is the most popular method (unless otherwise stated).

Accuracy

Using databases for the emissions calculations of some products means that there will be minor discrepancies. Assumptions are made if they err on the side of caution—if they exaggerate as opposed to minimising the worst possible result. An example of these discrepancies in emissions can be seen when one uses a CO2e/kg value for commercial hardwood harvesting when this project used local green lumber from a small mill. The ash wood was never kiln-dried and it was only transported a short distance, likely giving it an emission factor lower than that listed on the ICE database. Further, the wool was woven by hand in Toronto, using little to no electricity. Not having a dedicated metered connection during furniture construction means electricity use must be estimated from hours of tool use. Time was estimated to the closest half-hour of work and these values were generally rounded up.

This project produced experimental prototypes; therefore, tools were used for more hours than would be required if the furniture had been produced commercially. A key goal of the project is to develop a visualisation of carbon emissions for a given design— even the approximation of data is a step above what is currently expected.

Expected Results

The process of documenting and communicating components at the production stage of the project should strongly influence the thinking that occurs in the design phase—choosing a material based solely on its visual appeal or cost will be discouraged. Knowing that the final product will display the embodied carbon and estimated lifespan encourages more profound thought at the design stage. Logistics such as the distance to source materials, transportation methods, waste from production, and overall build quality will become a greater consideration at earlier design stages. Preliminary research shows that current rating systems are on two ends of a spectrum—from very complex life cycle assessments to rating systems which can be potentially manipulated. It is expected that a complete life cycle assessment for the proposed furniture will prove to be an intensive addition to the design process—one that may not be realistic for the average designer or small business. The desired result is that the design experiments expose ways to make life cycle assessment more accessible to designers. The proposed method should produce four functioning furniture prototypes: each prototype will be given a label with an accurate and clear descriptions of their entire lifespans.

Material Properties & Sourcing

2.

Section Contents

Figure.5 *Halliburton Forest, Living Woodwork*

“If a tree falls in the forest there are other trees listening”

Peter Wohlleben,
The Hidden Life of Trees

Chapter 2 – Materials, Processes, & Sourcing

In the book *The Hidden Life of Trees*, Peter Wohlleben discusses how trees communicate, share resources, and even develop relationships. Trees are far more than a construction material; they are ancient organisms far more capable than they are given credit.

Wood as a Material

This chapter outlines the common elements in subsequent sections relating to wood. It primarily discusses how the timber for this project was acquired, the wood’s physical attributes, the fabrication processes that the wood undergoes, and the science behind wood growth and bending.

There is merit in fully understanding the material one is using as an architect, designer, or maker; it allows one to appreciate both the strengths and limitations of a design and develop an appreciation for the resources one is taking.

The instructions in this chapter were developed through experience. Initial research uncovered approximate rules, such as one hour of steaming per one inch of thickness. Stream-benders commonly know these rules of thumb, making it hard to attribute to a single author. Various online sources and videos were viewed to establish a base knowledge of the practice.

Figure.6 *Living Woodwork, Photo by Author*

Figure.7 *A&M Specialty Wood, Photo by Author*

Selecting Timber

The first piece of lumber purchased was beech from A&M Specialty Woods, located in Preston, Ontario, seven kilometers from the Waterloo School of Architecture. The beech wood that A&M had available was European Beech from Germany. I was reassured it was from a sustainably managed forest, but it is still unfortunate that the timber was shipped across the Atlantic to a place already abundant with the same material. Time is always a factor; the relationship between sustainability and expedience was considered. As a researcher, it is easy to advocate for a more sustainable option but requiring the product to be created on schedule certainly puts a realistic perspective on things. I bought a single board of European beech 4/4 x 6" x 6' (25mm x 150mm x 1800mm) to stay on schedule but was aware that it would not be an option going forward.

Once settled in Minden, where the furniture is built, lumber was picked up from the Haliburton Forest and Nature Reserve. After communicating with their research director, a trip was planned to visit the workshop/mill, a half-hour drive from Minden.

The FAS (firsts and seconds: lumber grade) wood from A&M was a uniform, tight-grained, pale cream-coloured piece of wood. The wood from the Haliburton Forest was more affordable, rough-cut, and varied in colour. Wood that is dried too quickly often cracks on the surface; this is known as checking. Beech, being so hygroscopic, is prone to deformation and cracking. Pieces of wood were carefully selected to avoid knots and cracks. At this stage, a balance was sought between cost, sustainability, and quality. The entirety of the board from A&M could be used, while the boards from Haliburton needed planing, squaring and selective cutting. Part of the process involved asking: what amount of discolouration or defects in the wood is acceptable when the benefit is less waste? Knots and cracks were avoided because they would not handle the stresses of bending. Pieces that were discoloured enough to distract from viewing the object were excluded. This does mean embracing the natural grain and colour changes that occur in wood.

After some difficulty in bending the beech, it was decided to seek green lumber that had not yet been dried. The Haliburton Forest informed me that there was a newly fallen ash tree that could be cut to size and would be suitable for bending. The beechwood was still used for bending moulds and any straight elements in the furniture. Ash was reserved for bent components. Boards of dried ash were also purchased for the surface of the desk. The green ash bent exceptionally well. After planing and sanding, both species of local Ontario wood revealed a beautiful wood grain.

Figure.8 *Variation in Beech Wood (a) Haliburton Forrest (b) A&M Specialty Woods*

Figure.9 *Rough Cut Beech with Surface Checks, Photo by Author*

Figure.10 Bending Strap & Form, Photo by Author

Figure.11 Bending Strap & Form, Photo by Author

Figure.12 Steam Box, Photo by Author

Figure.13 Steam Generator Connection, Photo by Author

Bending Wood

Why Bending

Life Cycle Assessment involves carefully considering the process and the different phases of a project, instead of mainly focusing on the final product. One may choose local and sustainable materials but still process them in an unsustainable way. For the furniture, glue and steel fasteners were identified as components with high emission factors (Suh, 2010). Steam bending and wood joinery were chosen as a process that would improve the score on the label by reducing glues and metals. The bent members developed a visual language for this line of sustainably designed products and reduced the need to create joints. The process becomes relevant when discussing the environmental impacts of making; steam bending is a traditional practice involving natural fabrication methods not generally seen at an industrial scale.

How to Steam Bend

The steam bending process requires five components: green to air-dried lumber, a steam generator, a steam box, bending forms, and compression straps. Air-dried lumber at no less than 12-25 per cent moisture content is a good compromise between bendability and a fast-setting time (Veritas Tools Inc, 2011). Green lumber bends very well but may require extra time on a form to set and dry. The steam generator used was commercially available; it consisted of a heating element, a water container, a hose, and a threaded attachment. The hose can be run to the back of the steam box. The box is 6 inches (15cm) wide, 4 inches (10cm) tall, and 6 feet (180cm) in length. The back end of the box sits on legs that are shorter than the front. The resulting angle lets condensed water exit through a drip hole. The raised front has a hinged door with weather stripping and a latch. Perpendicular to the length of the box, there are dowels to elevate the piece that is being steamed, allowing for vapour to circulate fully. There is a hole partway down the box to insert a thermometer; the box must be preheated to

Figure.14 *Moisture Meter Reading %15, Photo by Author*

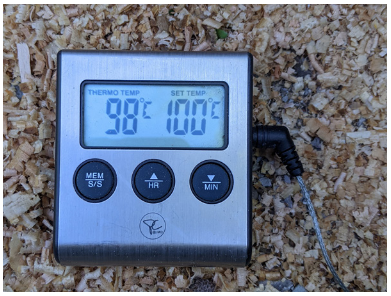


Figure.15 *Thermometer Reaching 100 C, Photo by Author*

Figure.16 *Bending Forms, Photo by Author*

Figure.17 *Completed Bends, Photo by Author*

100 degrees Celsius and remain at that temperature for one hour per inch (2.54cm) of the wood's thickness.

The bending forms were made of scrap hardwood glued and screwed to a plywood base to create the necessary curves. The forms undergo repeated and heavy stresses, so a strong form that avoids composite materials like MDF is recommended. The final angle of the bend should be exaggerated by about 15 per cent to account for spring-back (the tendency for the member to return slightly to its original shape). It is essential to understand that wood is a natural and unique material that differs from piece to piece; therefore, spring-back is not entirely predictable and should be accounted for in the final design.

The last component, the compression strap, helps prevent the wood from cracking. It is a metal band, ideally the width of the piece itself. It has blocks of wood bolted at either end of the strap with the same thickness as the bending piece. Long handlebars (3ft /~1m) are bolted to the end blocks to help bend the steamed wood. The longer the bar, the more leverage one has to complete a challenging bend. When bending any straight member, one face is forced into tension and the other into compression. The compression strap constrains the outer face of the wood, encouraging the inner face to compress. It is advisable that the metal is sealed in some way because the steel can stain the wood blue; a foil duct tape was used as a barrier.

Once the wood is steamed, the bend needs to be completed in no longer than five minutes (depending on room temperature); otherwise, the piece will have cooled to the extent that it can no longer be bent. If the member is being bent 180 degrees, such as a "U" shape, the piece should be placed in the bending strap and centred and clamped on the mould; at this point, it is helpful to have two people bend either end of the wood, fastening clamps as needed. A single person can complete bends with one curvature that is 90 degrees or less; These bends are put through less stress than a 180 degree or greater bend. Once fully bent to the shape of the mould, the piece should cool for 24 hours and be dry before sanding/finishing (Veritas Tools Inc, 2011).

Figure.18 *Bending Straps, Photo by Author*

Tree Species

Figure.19 *Ash Tree, Photo by Author*

Figure.20 *Beech Tree, Photo by Author*

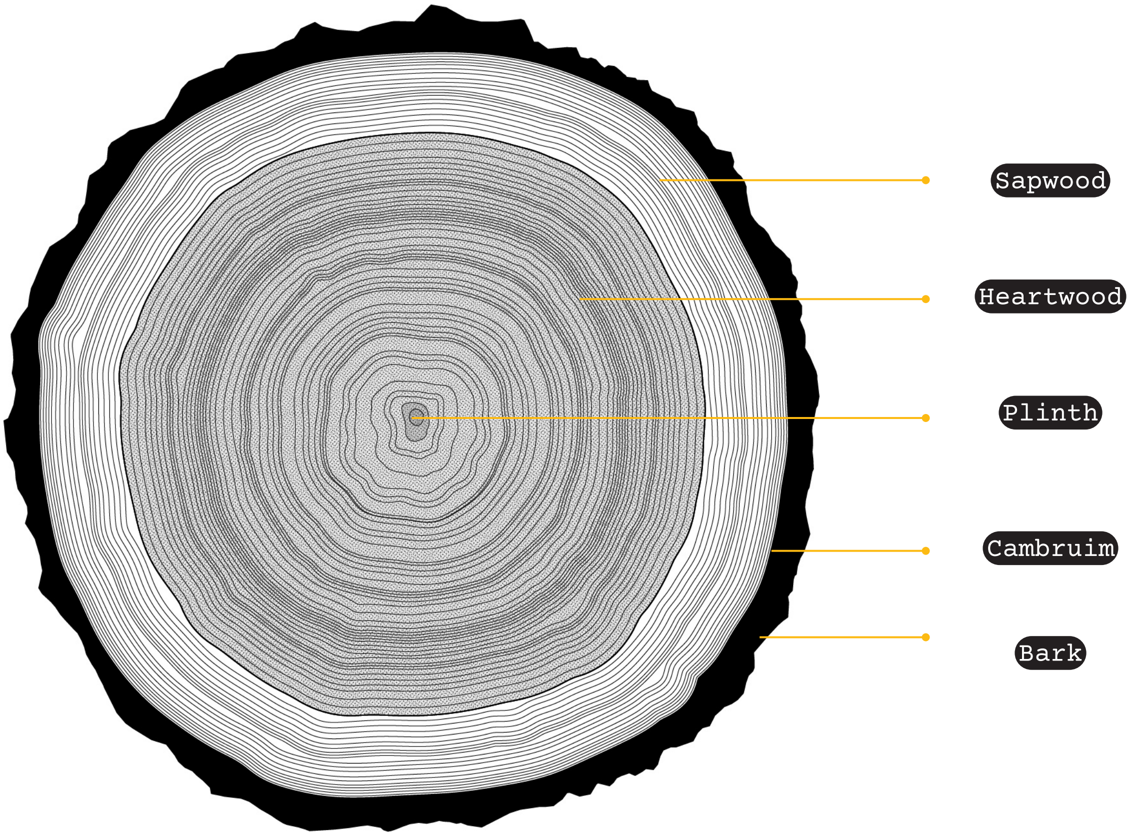


Illustration.3 *Tree Cross Section, Drawing by Author*

Based off information from: (Dinwoodie, 2000)

Wood Properties

Wood at a Human Scale

Working so closely with both ash and beech woods, I have become intently aware of their traits as both a material and a living thing. As a material, I recognise the unique patterns of the grain, the colours of the sapwood and heartwood, and the nature of their growth rings. As a living thing, I make it a habit to look for the species when I am on a walk; they both have distinct bark that makes it easy to spot them from eye level. Beech bark is a smooth, light grey surface. White ash has deep furrowed grooves in its dark brown bark. Mature beech, however, can develop a rougher bark at the base of the trunk as the surface cracks open. Ash trees have smooth elliptic-shaped pinnate leaves arranged like a feather in a bunch along one stem. Beech leaves are also elliptic in shape, but with serrated edges, they alternate along the branch.

Identifying wood species as both a material and an organism is another way to connect oneself to an object and develop a deep appreciation for the object. Seeing living trees and understanding that they have grown for the duration of human life or longer before being transformed into lumber adds to their perceived value. Extending the process of design to the entire life cycle solidifies the importance of the natural environment and the value of the built environment. A lamp may have taken two months for me to build, but it took 100 years to grow the wood; it could be in use for at least 50 years and then take over 50 years to break down wood (Weedon et al., 2009), over 5000 years to break down landfilled PVC or HDPE plastics (Chamas et al., 2020). Before you know it, a simple object is the responsibility of multiple generations. How easily would one part with something that has such a long lifespan?

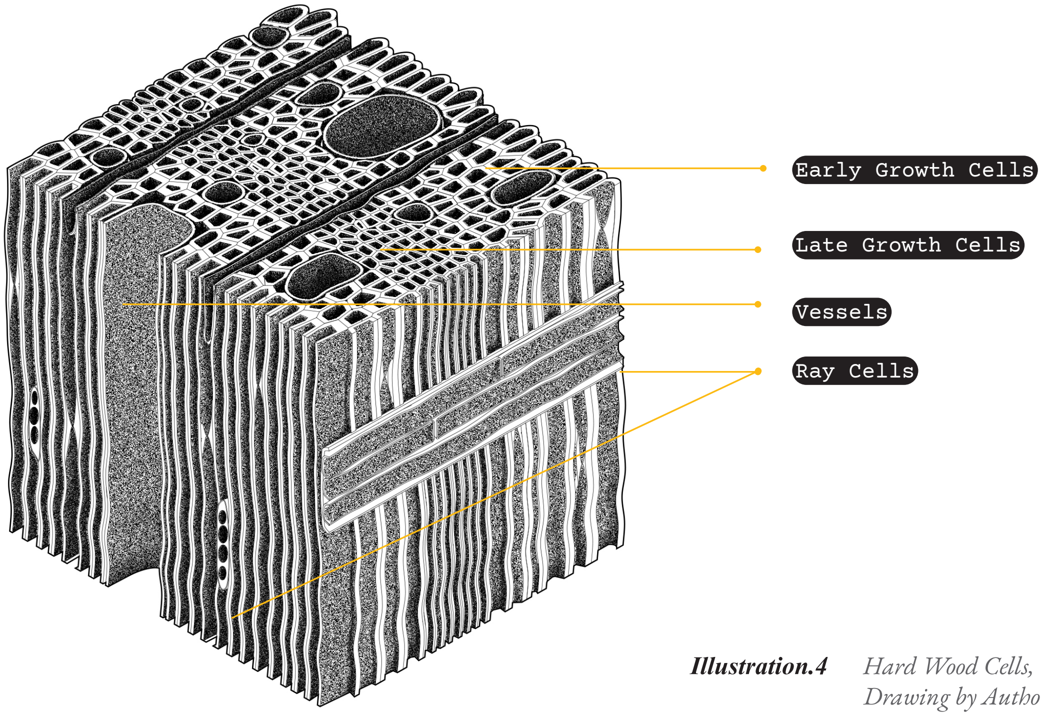


Illustration.4 *Hard Wood Cells, Drawing by Author*

Based off information from: (Dinwoodie, 2000)

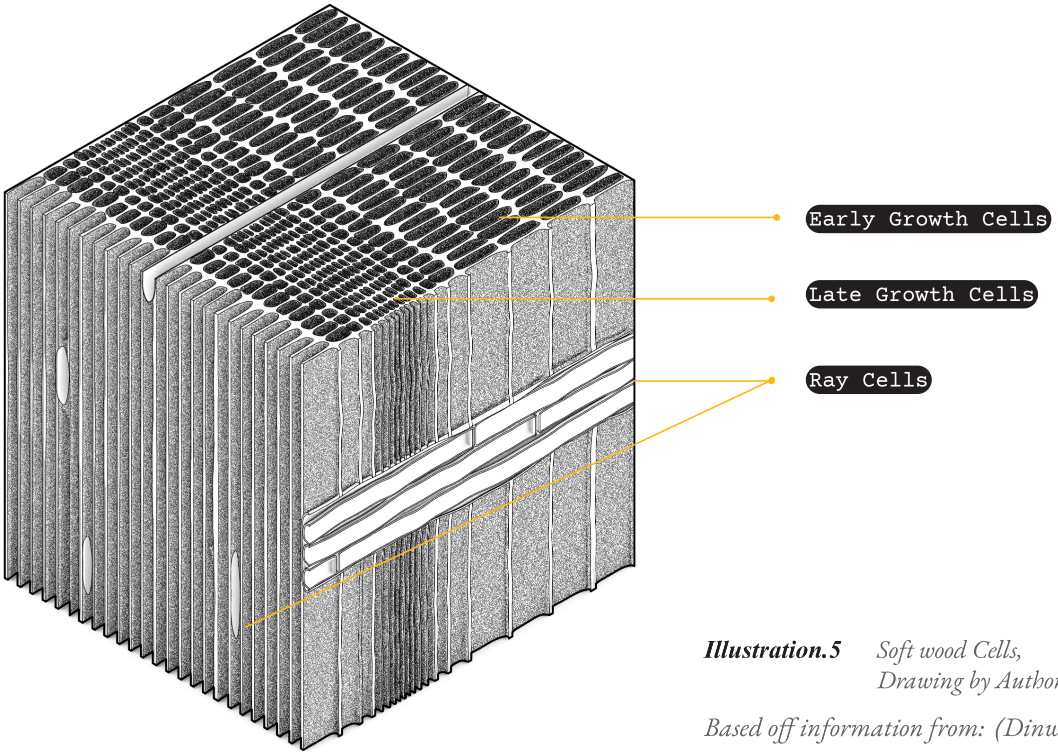


Illustration.5 *Soft wood Cells, Drawing by Author*

Based off information from: (Dinwoodie, 2000)

Wood at a Cellular Scale

As a maker, having a basic understanding of the cellular composition of wood provides clarity to how the wood appears and behaves—woodgrain results from the cell structure of trees and the growth patterns they experience over the years. To understand wood grain, it is vital to understand how trees grow. The wood portion of trees comprises two general types of cells, parenchyma and prosenchyma. Parenchyma cells are described as "food storage cells", and they typically make up the rays of the tree (Kollmann & Côté, 1968). Rays can be seen in a cross-section of a tree as lines that run perpendicular to the rings from the tree's exterior inwards. Rays are important in design because wood is more likely to split or check along the rays. Prosenchyma are woody vascular cells visible as rings in the cross-section of the tree. During the early season, these cells are more porous and oblong, while in the late season, they grow more dense and circular (Kollmann & Côté, 1968).

The wood for this project comes from Central Ontario, Canada, where there are distinct seasons that create a clear ring pattern and give the wood its pronounced grain. Also relating to design at the cellular level is the concept of heartwood and sapwood, its most significant effect being a difference in the wood's colour. From exterior to interior, the tree trunk consists of bark, the cambium (an outermost layer that is actively producing new cells), the sapwood, the heartwood, and the plinth (original centre). The sapwood contains living cells and transports nutrients throughout the tree, while the heartwood is composed of primarily dead cells. These dead cells give the tree its strength. As the tree grows, it constantly creates new cells in the cambium that later transition into the sapwood, eventually dying and becoming heartwood (Kollmann & Côté, 1968).

Relating to the species that the furniture is made of, I now understand early and latewood cells that give the ash its strong contrasting grain, and for the beechwood, I realise it has rays that are thicker than other species giving it the distinct fleck pattern and making it more prone to cracks.

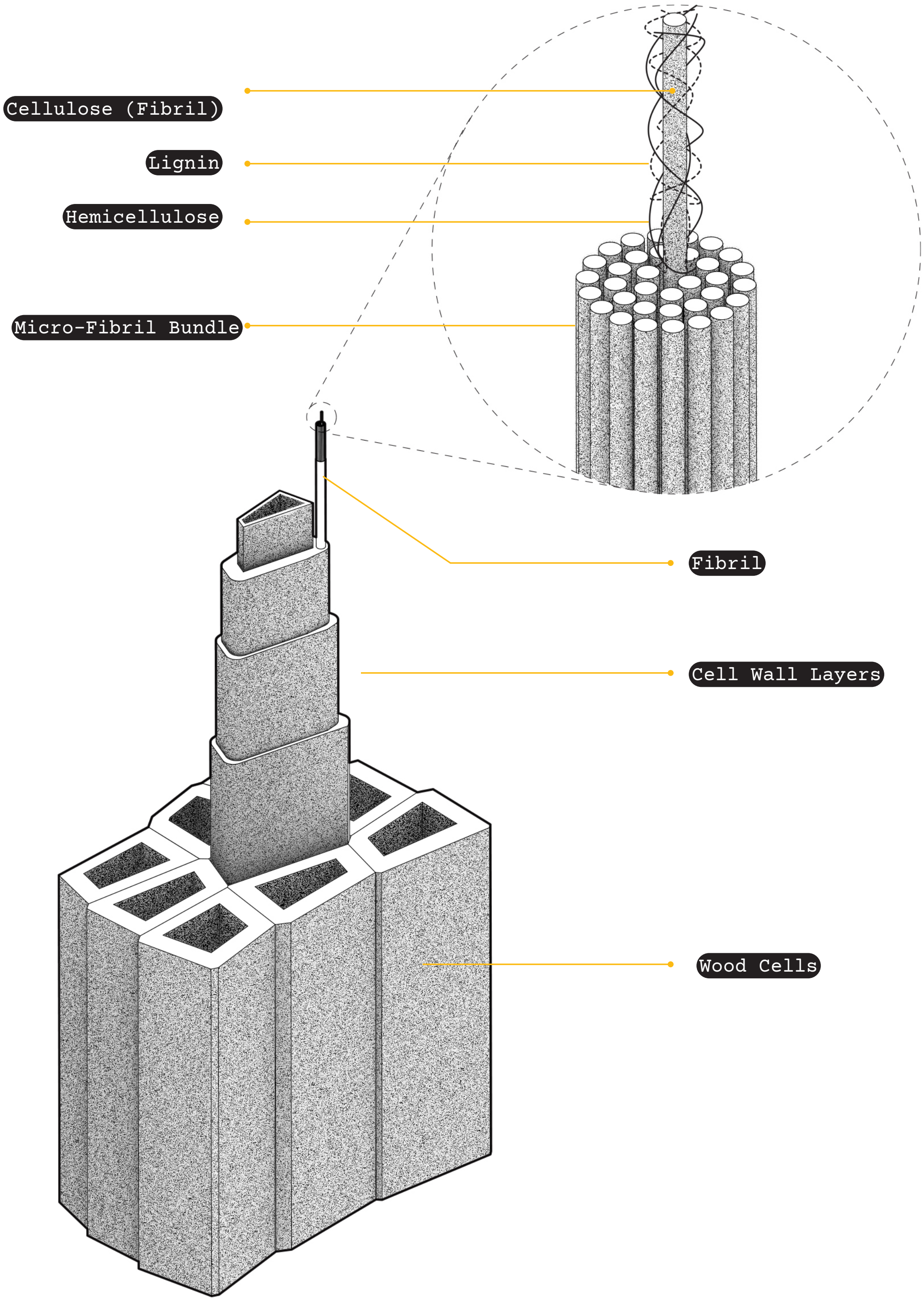


Illustration.6 *Schematic Wood Cell Molecule Diagram, Drawing by Author*
Based off information from: (Dinwoodie, 2000)

Wood at a Molecular Scale

In the context of architecture and design, understanding the cellular level of wood is likely far further than most will investigate, but because of the nature of steam bending wood, one must go to the molecular scale to answer the question: how does solid wood bend? The walls of the prosenchyma cells are made up of three primary components: cellulose, hemicellulose, and lignin. Cellulose occurs in the form of macro and microfibrils; this form gives wood its structural properties. The strength of wood can be attributed to lignin, a "three-dimensional polymer" that is found in between cellulose fibrils, essentially tree glue (Kollmann & Côté, 1968). Lignin is the key to bending solid wood. Moisture and heat are the two factors that relax the lignin and permit the cellulose fibrils to bend. "The glass transition temperature (Tg) of the lignin in moist wood is 80–100 °C. Above Tg, the lignin undergoes thermoplastic flow and resets in the modified configuration when cooling (Nakajima et al. 2009; Ibach 2010; USDA 2010)" (Börcsök & Pásztory, 2021) If the raw material has a 20–25% moisture content, no additional moisture is needed, even for severe bends (Peck 1957)." (Börcsök & Pásztory, 2021). Heat and water are what make steam the perfect candidate to plasticize wood and why air-dried to green lumber at 12-25% moisture content is ideal for bending

Species	*Moisture content*	*Specific gravity*	*Modulus of rupture (kPa)*	*Modulus of elasticity (MPa)*	*Work to maximum load (kJ/m3)*	*Impact bending (mm)*	*Compression parallel to grain (kPa)*	*Compression perpendicular to gain (kPa)*	*Shear parallel to grain (kPa)*	*Tension perpendicular to grain (kPa)*	*Side hard (N)*
Ash	Green	0.55	66000	9900	108	970	27500	4600	9300	4100	430
Ash	12%	0.60	103000	12000	115	1090	51100	8000	13200	6500	5900
Beech	Green	0.56	59000	9500	82	1090	24500	3700	8900	5000	3800
Beech	12%	0.64	103000	11900	104	1040	50300	7000	13900	7000	5800

Figure.21 *Ash and Beech Technical Properties*

Data from: (Wangaard and Garratt, George A. (George Alfred) 1950)

Lamp

3.

Section Contents

Illustration. 7 *Original Rendering of the Lamp, Visualisation by Author*

> ***“We will make electricity so cheap that only the rich will burn candles.”***
>
> Thomas Edison

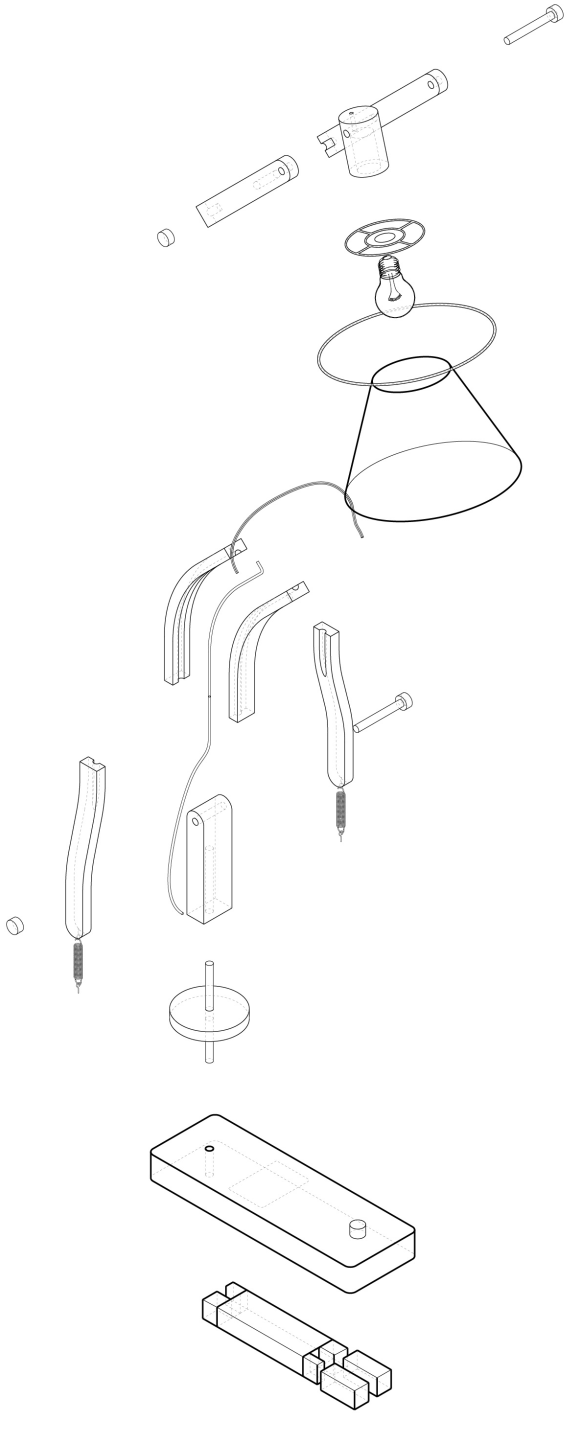
Chapter 3 – Lamp Case Study

Light has always been a powerful design tool. Natural and artificial light can transform a space, completely altering the atmosphere of a room. Sources of artificial light enable us to extend the day, a comfort we frequently take for granted. Edison’s goal was certainly achieved; the cost to operate modern LEDs is a fraction of burning a candle. However, the affordability of electricity has proliferated electronics that have created environmental costs to the planet. The modular design of this lamp aims to create a long-lasting product that takes advantage of efficient lighting technology.

Artefact Description

The goal of the lamp design was to create one light fixture that could function as three types: a desk lamp, a floor lamp, and a wall sconce. The modular construction is accomplished by using a system of 12V DC jacks and plugs that allow the lamp to be disconnected and reassembled in various configurations.

From its original state as a desk lamp, a single steel rod allows the lamp to be removed from the base and mounted on a separate tripod to transform into a floor lamp. The head of the lamp can also be removed and attached to a wall mount to become a wall sconce. This adaptable and malleable design extends the lamp’s lifespan in two ways: one, it allows individual components to be replaced instead of discarding the whole lamp. Two, knowing that the lamp can perform at different scales depending on the requirements of the occupied space, the user is incentivised to keep the item longer.



LED bulbs and a 12V LED driver were chosen for energy efficiency and electrical safety. LEDs are a highly efficient upgrade for lighting, requiring only a 12V or 24V power supply instead of the standard 100 to 240V power supply delivered to outlets around the world (120V in North America) (Cangeloso & Jepson, 2012). A LED driver was used to drop the voltage.

Illustration.8 *Lamp Configuration Drawing, By Author*

Orthographic Drawings

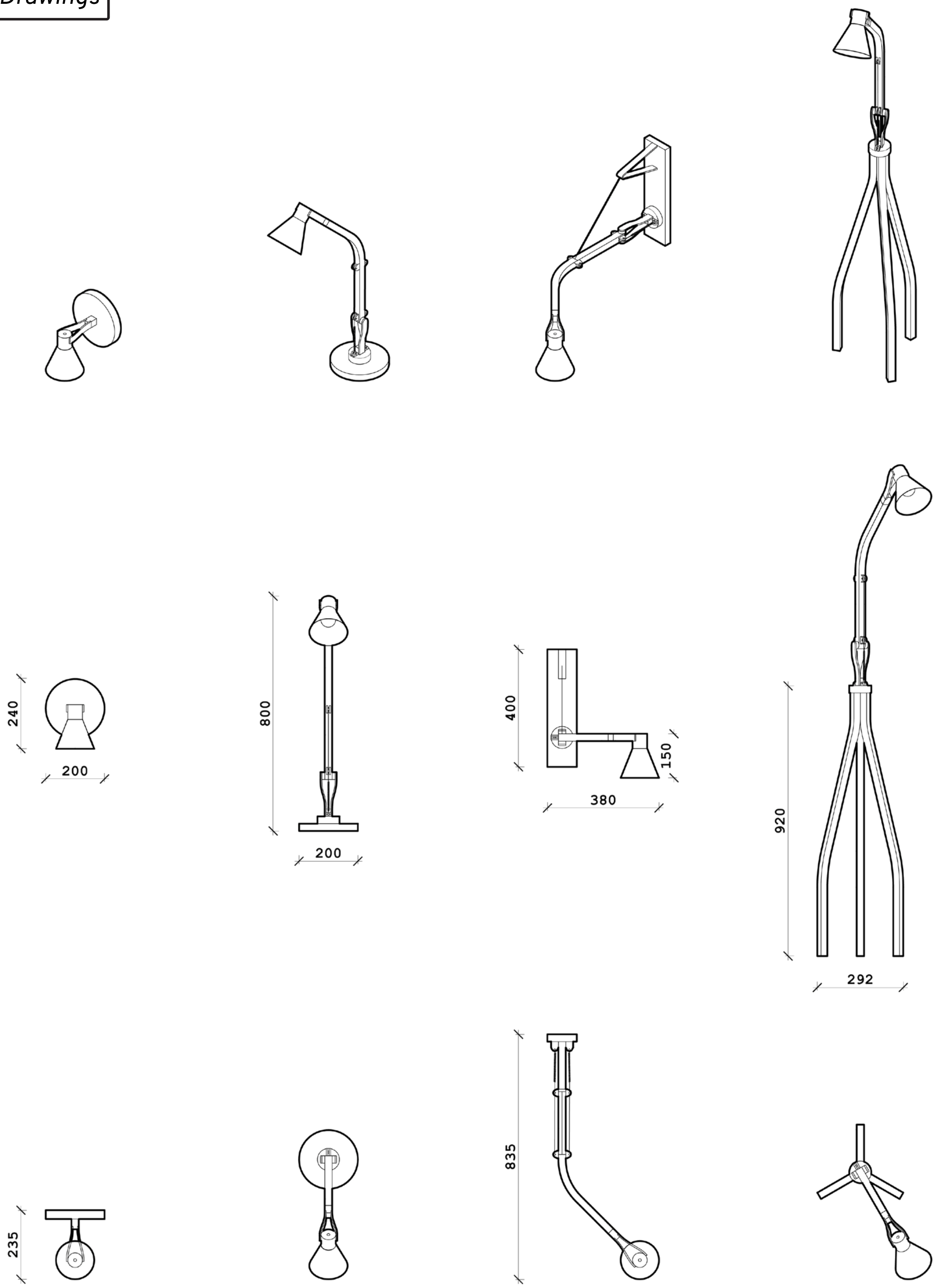


Illustration.9 *Lamp Exploded Axonometric Drawing By Author*

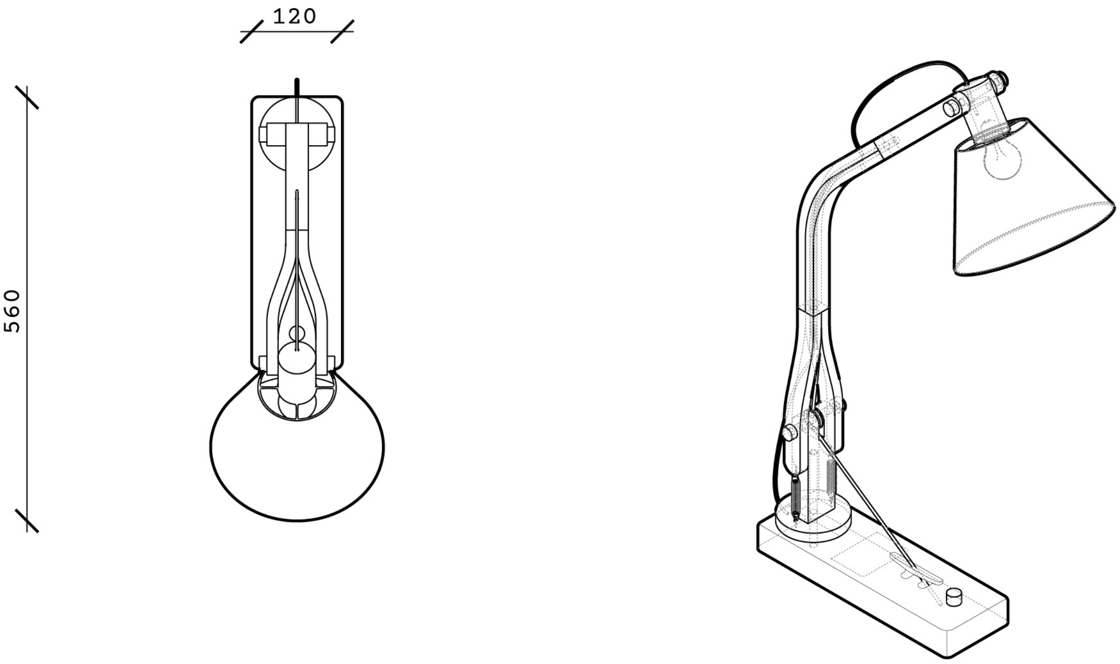


Illustration.10 *Lamp Plan and Axo, Drawing By Author*

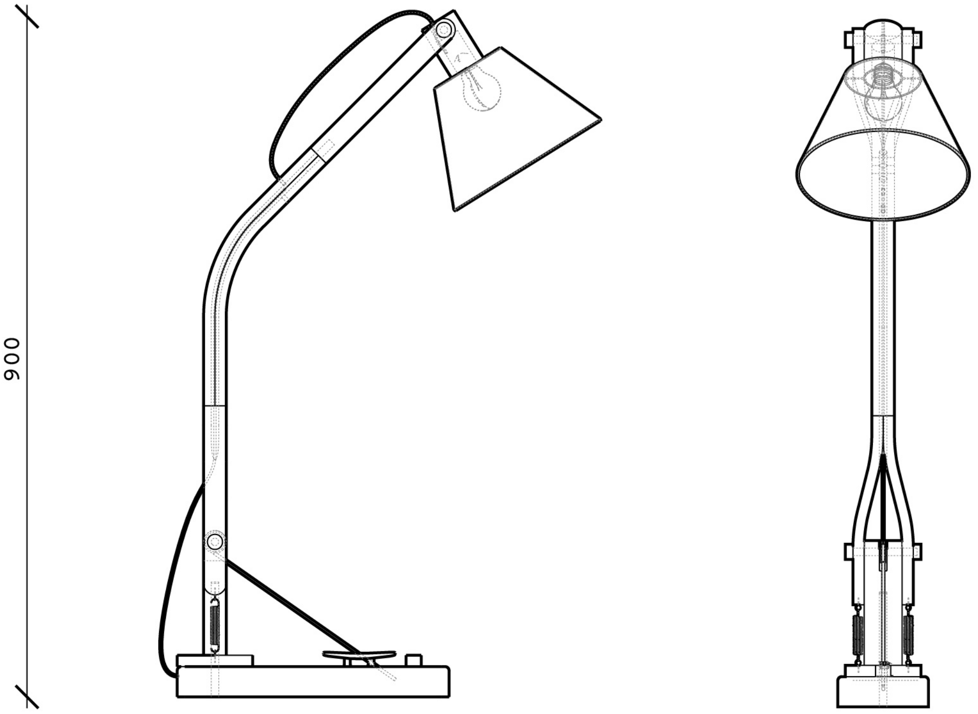


Illustration.11 *Lamp Elevations, Drawing By Author*

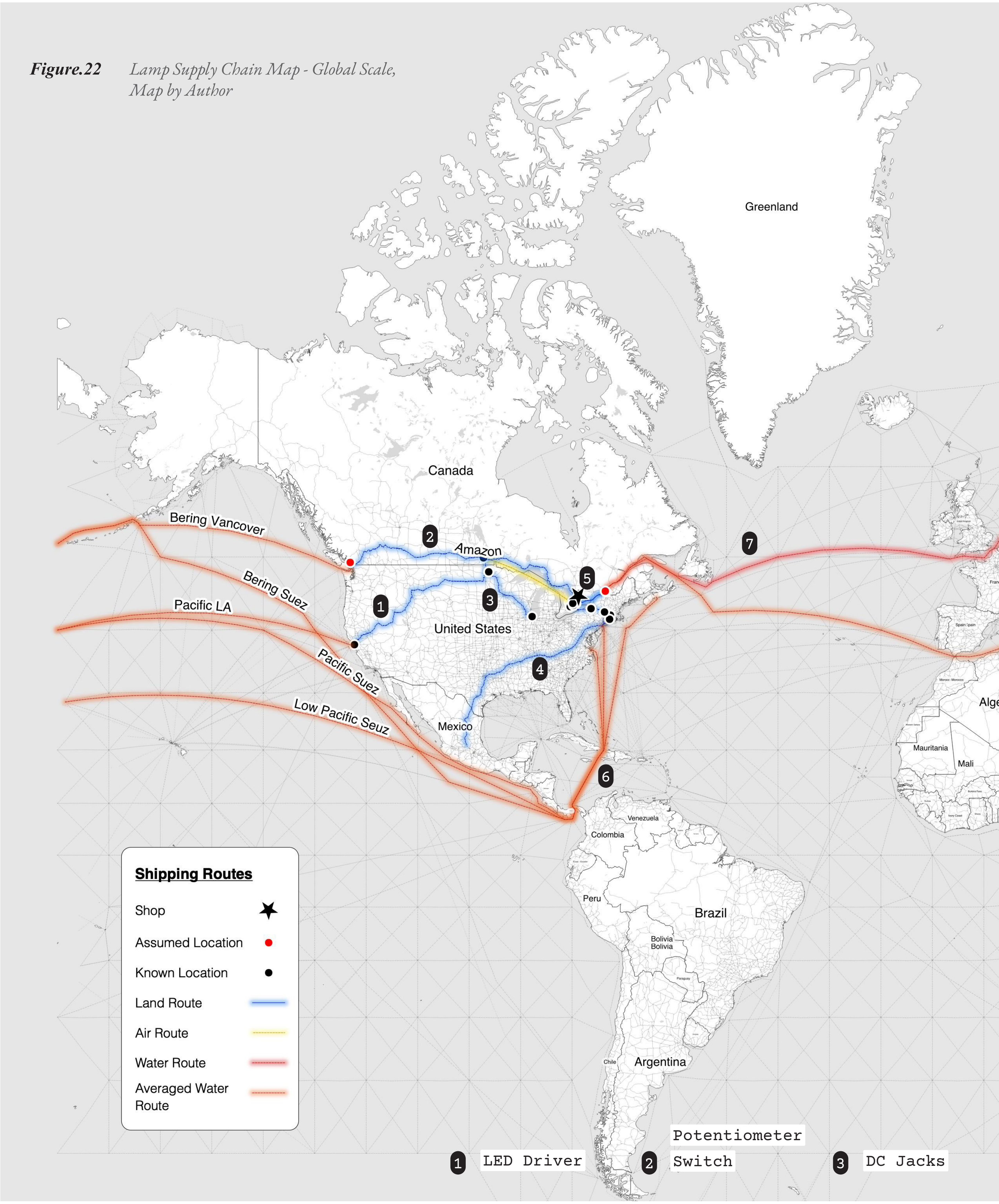


Figure.22 *Lamp Supply Chain Map - Global Scale, Map by Author*

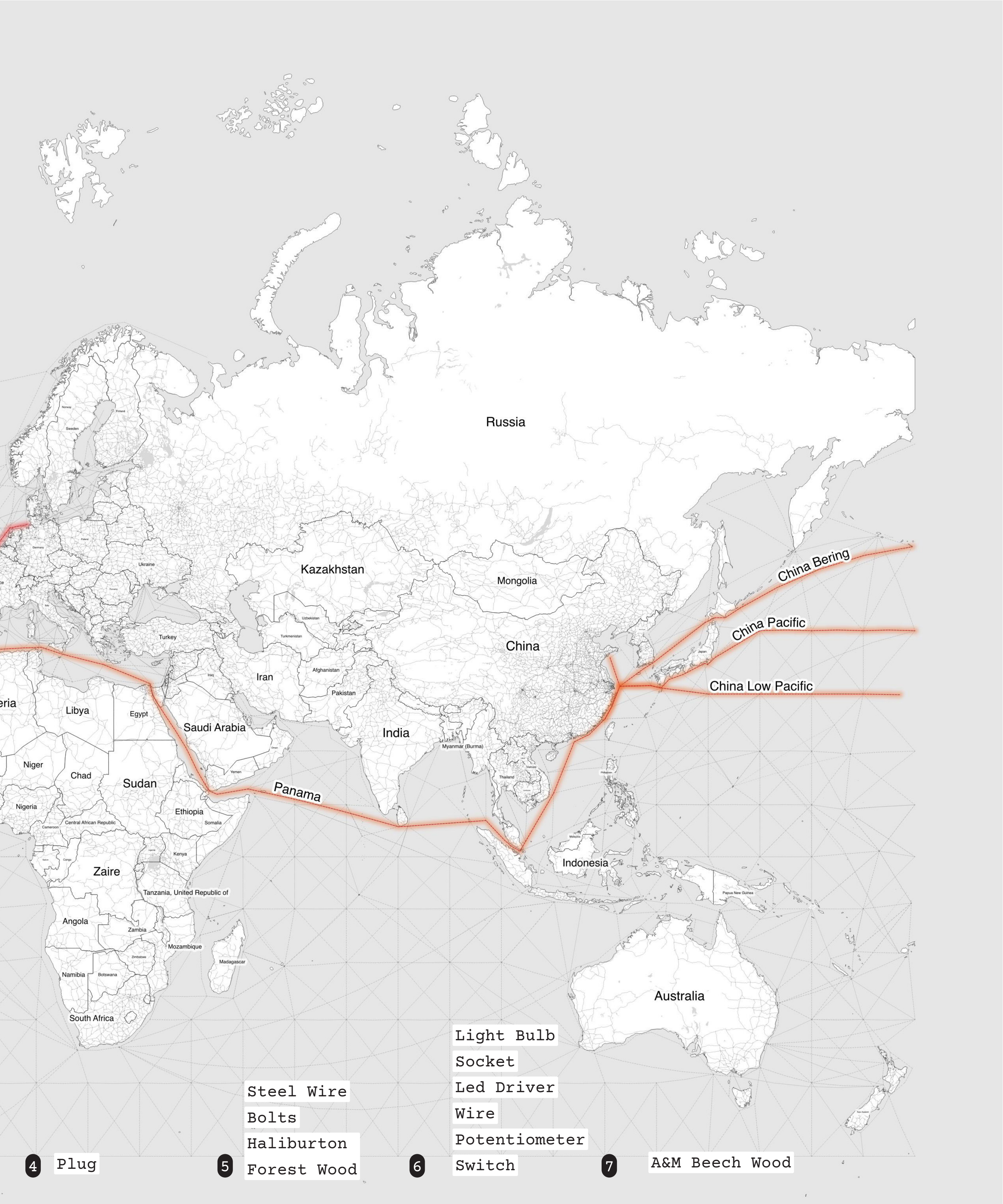

Russia
Kazakhstan
Mongolia
China
China Bering
China Pacific
China Low Pacific
Ukraine
Turkey
Uzbekistan
Turkmenistan
Iran
Afghanistan
Pakistan
India
Myanmar (Burma)
Thailand
Japan
Indonesia
Papua New Guinea
Australia
New Zealand
Saudi Arabia
Yemen
Oman
Iraq
Egypt
Libya
eria
Niger
Chad
Sudan
Nigeria
Ethiopia
Somalia
Central African Republic
Cameroon
Kenya
Zaire
Tanzania, United Republic of
Angola
Zambia
Zimbabwe
Mozambique
Madagascar
Namibia
Botswana
South Africa
Panama
4 Plug
5 Steel Wire
Bolts
Haliburton
Forest Wood
6 Light Bulb
Socket
Led Driver
Wire
Potentiometer
Switch
7 A&M Beech Wood

Figure.23 *Lamp Supply Chain Map - North American Scale, Map by Author*

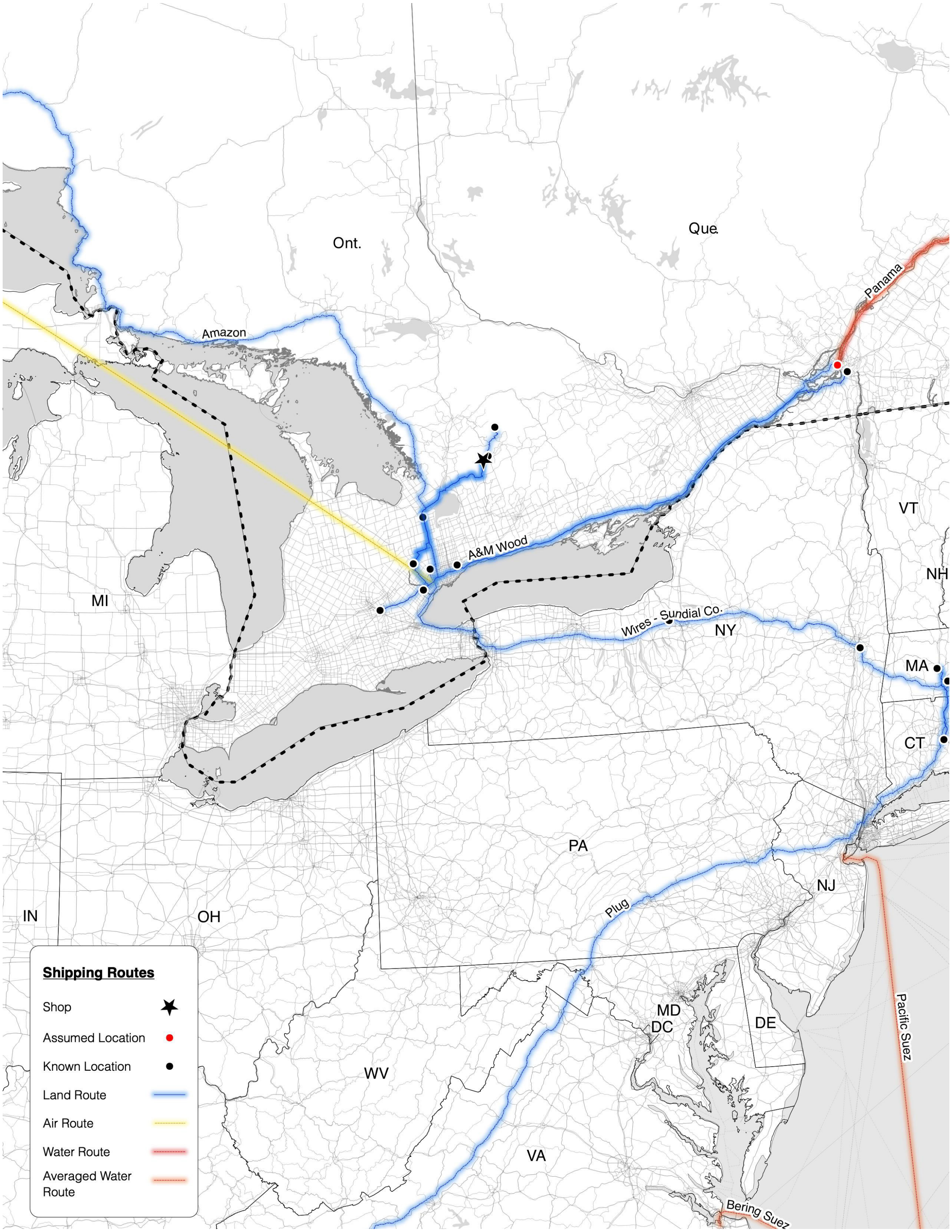
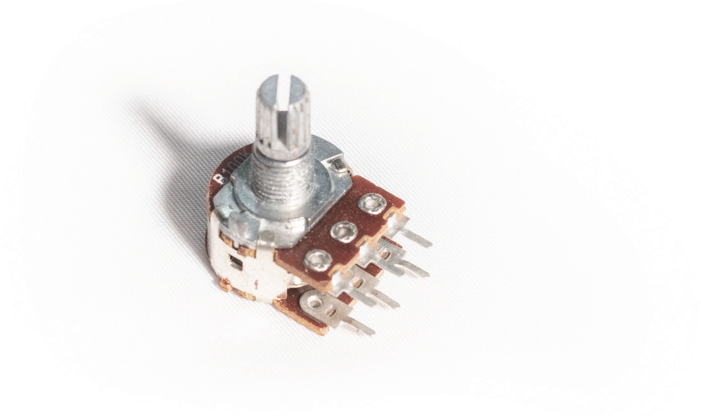


Figure.24 *Lamp Supply Chain Map - Provincial Scale, Map by Author*

Lamp Parts Catalogue

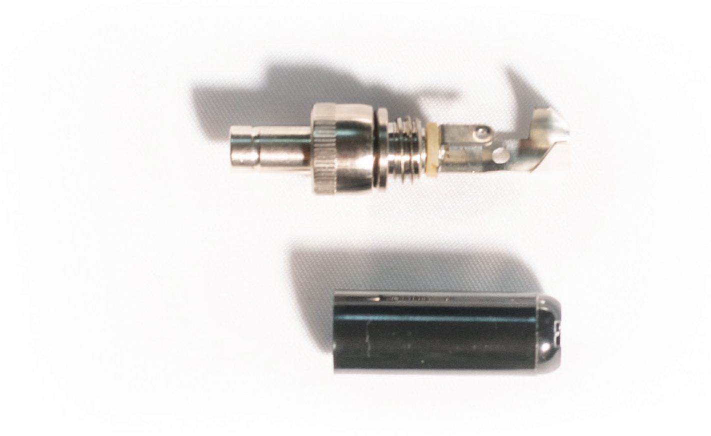


100 ohm. Potentiometer (diming)

Scale Bar (cm)

1 2 3

Figure.25 *100 ohm Potentiometer, Photo By Author*



12v DC Plug

Scale Bar (cm)

1 2 3

Figure.26 *DC Plug, Photo By Author*

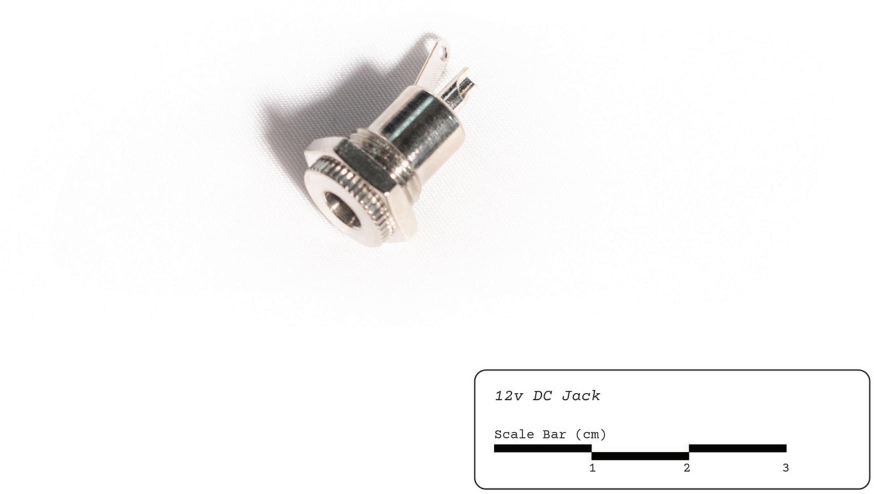


Figure.27 *12v DC Jack, Photo By Author*

Figure.28 *MR16 Light Bulb, Photo By Author*

Figure.30 Half of Bend Lamp Arm, Photo By Author

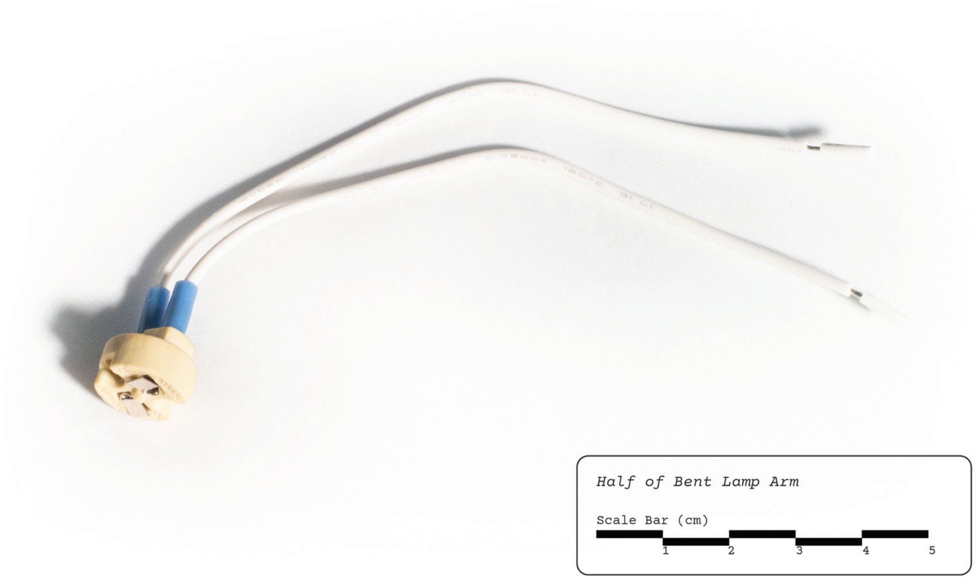


Figure.29 MR16 Light Socket, Photo By Author

Figure.32 *Wishbone Lamp Arm Connector, Photo By Author*

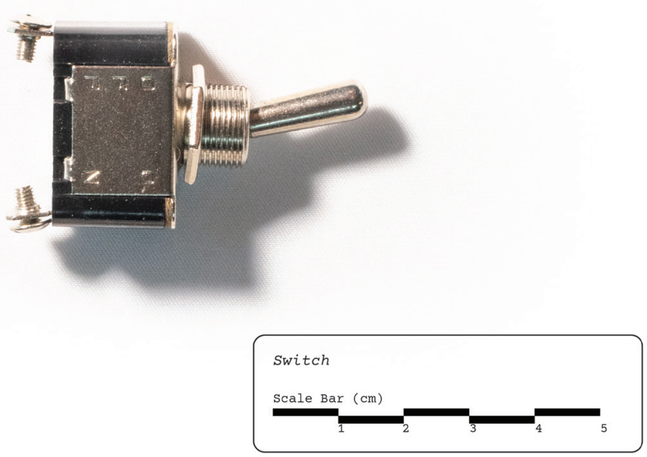


Figure.31 *Switch, Photo By Author*

Figure.34 *Lamp Head with Shade, Photo By Author*

Figure.33 *Lamp Head Frame, Photo By Author*

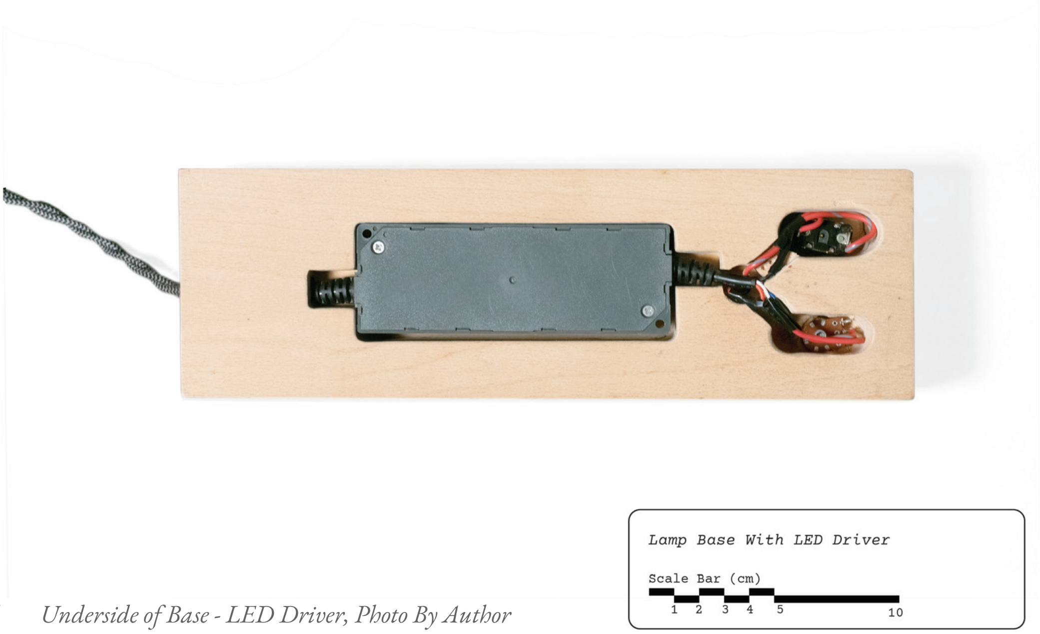


Figure.36 *Underside of Base - LED Driver, Photo By Author*

Figure.35 *Braided Electrical Cable, Photo By Author*

Figure.37 *Threading Wire Through Lamp Arm, Photo by Author*

Figure.38 *Attaching Wishbone to Lamp Body, Photo by Author*

Figure.39 *Initial Failed Bend, Photo by Author*

Figure.40 *First Successful Bend, Photo by Author*

Figure.41 *Assembled Lamp Base, Photo by Author*

Construction Process

The lamp was the smallest and the most intricate case study artefact. It presented the greatest learning curve when bending wood and assembling electrical components. The lamp's base was the first component built; it incorporated a complicated space that needed to be precisely routed out so the dimmer, the switch, the DC Jack, the LED driver and all the corresponding wires could be located. A rotating vertical piece was inserted into the base via a steel rod. This component served as the point where the steam-bent arms would attach and allowed the lamp to change positions.

Wood Bending

The following components to be built were the steam-bent sections of the lamp arm. The initial process took practice and patience to produce successful bends. Bending the piece of wood without compression straps failed due to breakage. The second bend was completed with a compression strap, and while the wood was able to bend further, it still eventually split. The third bend used wood from a local sawmill at the Haliburton Forest. It was stored outside and was more recently cut, giving it a higher moisture content, which contributed to achieving a successful bend. Moisture content for wood bending is ideally 12 per cent or higher. Wood dried for long periods and stored indoors can reach 2 per cent moisture content, at which point it is nearly impossible to bend. The wood from A&M was too dry to bend.

On the first successful bend, the spring-back was slightly over-calculated, resulting in a greater bend than needed. Secondly, the heat and moisture caused the steel bending strap to rust and oxidize onto the wood, turning it a grey-blue colour in areas. The marks could be sanded out or removed with a cleaner that contained Oxalic Acid. After multiple attempts, the problem of unpredictable variations in spring-back was accepted. It was decided that while the body would still be steam bent, the minor components that connect the lamp to the shade and the base would be cut out of solid wood. This compromise

Figure.42 *Dried Paper Lamp Shade, Photo by Author*

Figure.43 *Removing Wet Pulp from Screen, Photo by Author*

created uniform pieces suitable for the connection components and let the lamp body (whose angle could vary) remain a steam-bent piece. The centre of the lamp's body was made from two steam-bent pieces with a channel routed in the centre. The channel was created before the piece was bent, and the two resulting pieces were glued together. A wire could now run through the hollow core.

Once all wood components were cut and bent, they were assembled with dowels, bolts, or glue. The sections in a fixed position were glued together with dowels, while the moving parts were connected with a bolt and wing nut to allow for movement at the base and the lampshade.

Lamp Shade

The lampshade was made from newsprint sawdust and wood shavings. These materials were readily available and considered waste products. Wood shavings and paper scraps were combined with water in a blender to make the pulp. A few batches of the mixture were created and added to a bowl. The pulp was washed to remove excess ink and then strained. A frame was built that supported a mesh screen stapled to its outer edges. A second frame was constructed to serve as a removable border for the first screen; the border allows for a clean edge and prevents the pulp from spreading beyond the extent of the first frame. This screen system can then be submerged in water, and the pulp mixture can be freely dispersed over the screen. When the frame is lifted from the water, the pulp settles in a thin layer on the screen. The border can then be removed, and the wet paper is left to dry. The sheet of paper was ironed, finely sanded, and cut into an arc shape. The lampshade was coated in a watered-down solution of PVA glue to stiffen it. The two ends of the arc-shaped net were glued together to create the final shape. The lampshade frame was constructed from five pieces of a steel rod; two circles connected by three vertical wires were all soldered to a large washer. Two holes were drilled into the washer so the shade could be screwed onto the lamp head.

Figure.44 *Blending Pulp, Photo by Author*

Figure.45 *Distributing Pulp on Screen, Photo by Author*

Figure.46 *Initial Sawdust on Screen, Photo by Author*

Figure.47 *Soldering Wire frame for lampshade, Photo by Author*

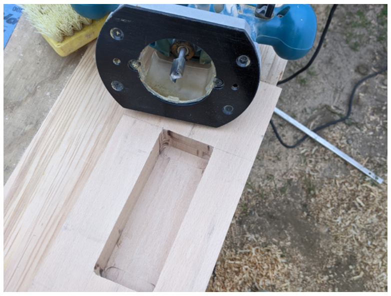


Figure.49 *Routing Out the Lamp Base, Photo y Author*

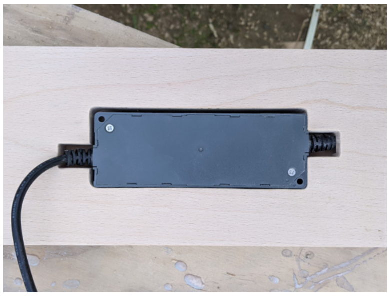


Figure.50 *LED Drive in Base, Photo by Author*

Figure.51 *DC Plug - Soldered, Photo by Author*

Figure.52 *DC Jack - Soldered, Photo by Author*

Figure.48 *Soldering DC Connection, Photo by Author*

Electronics

The electrical components were a challenge to conceal within the form of the lamp, and ensuring that they were compatible with one another added complications. Wires were cut to the required lengths, the plastic casing was stripped back, flux was applied to the bare wire, and soldered to the receiving connector or wire. One needs to work quickly while soldering—a few DC connectors overheated from being in prolonged contact with the soldering iron and broke apart. The driver, dimmer, and switch were concealed within the base. The socket was concealed in a cylindrical piece of wood containing a connection bolt and the light bulb. The initial bulb and socket were incompatible with the dimmer and driver combination. The bulb would buzz and flicker. The LED driver had a built-in PWM dimming function, this meant that a secondary dimmer was not needed, and dimming could be controlled with a 100-ohm resistance potentiometer. PWM stands for pulse wave modulation, and it is an efficient way to dim LEDs smoothly by rapidly turning on and off power at a rate the human eye cannot see. LEDs operate best receiving full power, so traditional resistance dimming (typically used on incandescent lights) is less successful with LEDs (Cangeloso & Jepson, 2012).

The successful bulb was a 12V MR16 dimmable LED. The potentiometer was about 2cm and fit well in the base next to a toggle switch. When the bulb continued to flicker, the circuit was tested with a LED strip light which dimmed successfully. This test confirmed that the LED driver was working correctly and that it would be more logical to try another light bulb. The successful bulb was a 12V MR16 dimmable LED. This change came with the benefit of a much smaller pin style socket. Despite abundant research, not all electrical components are designed to work together optimally. The extra components will be used in other projects and are accepted as a part of the research and development process.

Discussion & Analysis

Observations on the building process

Of the four designed pieces, the lamp took the most forethought. From

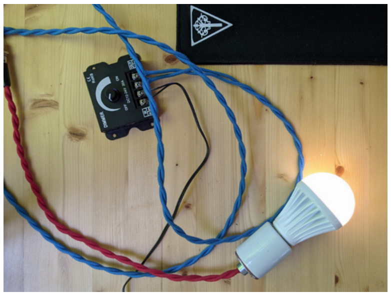


Figure.53 *Origional Bulb & Dimmer*

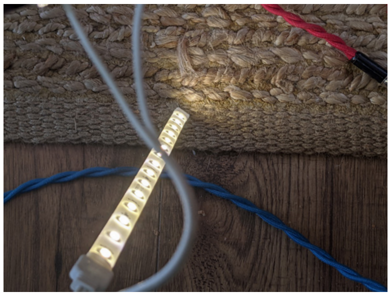


Figure.54 *Testing LED Light Strip*

Figure.55 *Final MR16 Bulb*

Figure.56 *Installed 12V Plug - Soldered, Photo by Author*

Carbon Label & Calculations

Carbon Facts

Item: Lamp

Weight (kg)	2.32	kg
Emissions / kg	3.17	CO_2e/kg
Total Emissions	7.38	kgCO_2e
Inc. Carbon Storage	4.18	kgCO_2e
% Yearly Value*	0.06%	
Production	3.785	kgCO_2e
Transportation	1.246	kgCO_2e
End-of-life	2.314	kgCO_2e
Operation (75yrs)	0.0116	kgCO_2e
Carbon Storage	-3.180	kgCO_2e

Lifespan Facts

Lifespan Goal	75	years
Cost / Year	2.4038	$/yr
Adaptability	Good	
Maintainability	Excellent	
Reliability	Fair	
Recyclable Parts	Very Good	
Biodegradable Parts	Very Good	

Certifications

Sustainable Forestry	✓
Fair Trade	✓
Safe Workplace	✓

Ingredients

Beech Wood, PVA Glue, Steel, Recycled Newsprint, Copper, PVC, Rubber, Cotton, Glass

Table.1 *Lamp Carbon Fact Sheet, Table by Author* top to bottom, wires and electrical components needed to be concealed within the wood form of the lamp. This level of intricacy took time and patience to assemble. The order of construction for the components was important too. Once glued together, it would be challenging to accomplish tasks like threading a wire through the lamp's arm or inserting the DC jacks. The electrical circuit was constructed in sequence from plug to bulb so that it could be tested each component was added. The wiring was tested separately before being incorporated into the lamp. In addition to the lamp's construction, several custom tools needed to be built during this phase, such as the steam bending box, bending straps, moulds, and the papermaking screen. The initial investment in production tools and test components is not incorporated in the carbon emissions but perhaps would be helpful as a future section on the label. Initial emissions from failed prototypes in the research and development phase would be large for the first round of production, but once a process is established, the proceeding items can be produced more efficiently.

Sourcing and ordering materials was a far more extensive job than initially planned. Serious consideration of the distance, material build quality, and the origin of manufacturing narrowed the available options. After completing this first design project, it would be advantageous to complete sourcing before or during the design stage. From experience, it is common in architecture to only source materials after the initial design is completed.

As the first piece constructed in the series, considerable time went into experimenting with steam bending and finding the correct tools for construction. While learning from mistakes and failures can be an invaluable experience, there is a cost in materials, time, and energy when participating in creating experimental prototypes. Knowledge sharing is a valid way of reducing emissions by avoiding redundant errors. Knowledge sharing and creation is an essential part of research. The book *Knowledge Sharing in Research Collaborations* reviewed the topic of collaboration. In the chapter on "knowledge", Niedergassel describes various types of research; this project falls into the category of *Experimental Development*, defined as: "systematic work, drawing on knowledge gained from research and practical experience, that is directed to producing new materials, products and devices" (Niedergassel, 2011). The practical experience gained from this building process has been tremendous and could be further developed through future collaborations.

Observations from the Data

The use of wood was the highest individual contribution to carbon emissions in the lamp. Despite smaller electronic parts being more carbon intense per kilogram, the weight of wood used was more significant than the weight of electronics and metals. The next two largest emissions were the LED driver, followed by an electrical wire. Wood's primary benefit is its ability to store carbon while in a preserved state; the ICE database estimates the carbon storage of hardwood to be -1.59 kg of carbon equivalent emissions per kg of wood. Left to decompose (not recycled), a large percentage of that stored carbon is released, 1.152 kg per kg of wood. If a wood product or architecture is maintained, it can be a carbon sink for its service life.

From a shipping emissions perspective, shipping by a deep-sea barge is very efficient. Lightweight electronics from China occupy a minimal amount of space on a shipping container, making them responsible for only a minor fraction of the journey's emissions. A half-hour drive in a gas car to pick up the lumber released nearly twice as much carbon as shipping the LED driver from China. When using a personal vehicle, this single project is responsible for the entirety of the journey's emissions, compared to the emissions of a barge shared over a multitude of projects. Relatively low emissions from overseas shipping were an unexpected result that proves that shipping in large quantities at a slower speed can be more efficient than a local pick-up in a gas-powered vehicle. Indeed, if a larger order of wood was picked up from a local supplier that would be used for multiple projects, the efficiency would improve. If the electronics were produced more locally, their emission would be even more negligible. The economy of scale can also be applied to carbon emissions.

The production of materials was the greatest emission, followed by shipping. Running electric power tools (on a relatively clean power grid) was significantly lower. Operating the light itself was almost negligible compared to the embodied energy needed to create the lamp. The low emissions from operation reinforce the idea that embodied carbon becomes a far greater concern when using efficient systems.

Emission Goals: Canada & Global

i

Canada pop	37590000	**World Pop**	7800000000
2030 Goal (Mt)	438	**2030 Goal (Gt)**	40
Kg	438000000000	**Kg**	40300000000000
Per Person	11652	**Per Person**	5167

ii **Product: Lamp**

Total Cost	180.29	**A Co2e**	Cradle To Gate (Production)	3.78
Total Weight	10.40	**B Co2e**	Gate to Point of Sale (Transportation)	1.04
Built Weight	2.32	**C Co2e**	Point of Sale to Site (Transportation)	1.58
Total Co2e	6.61	**D Co2e**	Construction	0.21
Stored Carbon	-3.18	**E Co2e**	Operation	0.0002
		F Co2e	End of Life	2.31
		G Co2e	Carbon Storage	-3.18

Table.2 *Summery of Data for Lamp, Table by Author*

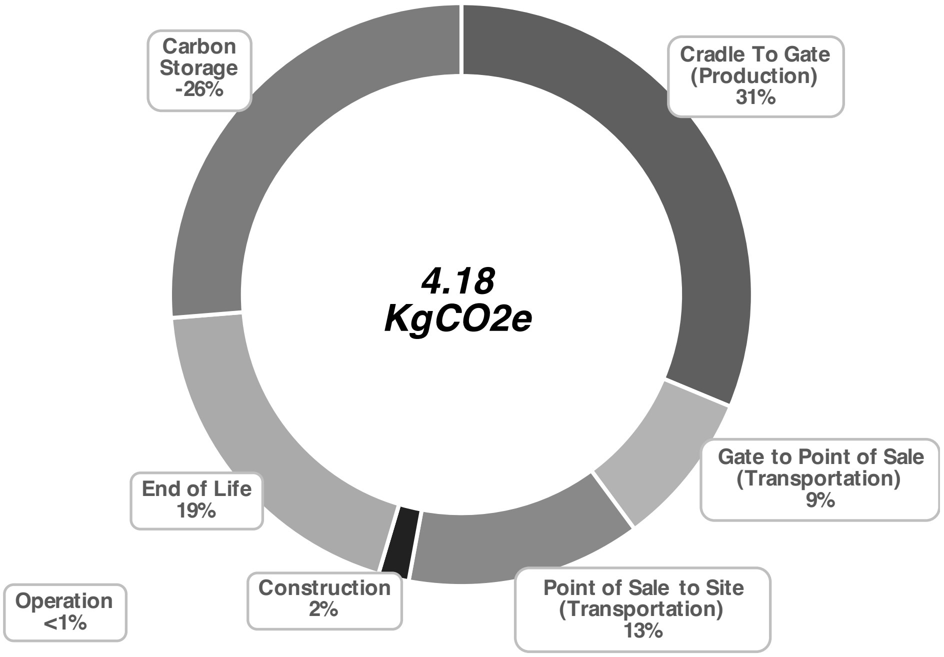
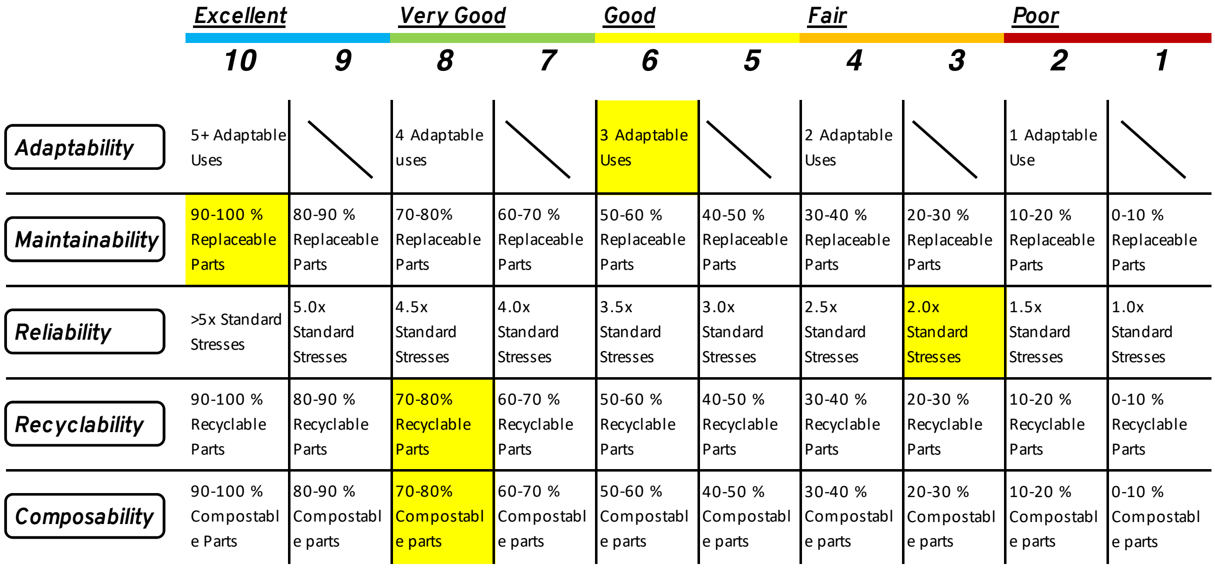


Table.3 *Lamp Emission Phase Breakdown*



	Excellent		Very Good		Good		Fair		Poor	
	10	9	8	7	6	5	4	3	2	1
Adaptability	5+ Adaptable Uses	╲	4 Adaptable uses	╲	3 Adaptable Uses	╲	2 Adaptable Uses	╲	1 Adaptable Use	╲
Maintainability	90-100 % Replaceable Parts	80-90 % Replaceable Parts	70-80% Replaceable Parts	60-70 % Replaceable Parts	50-60 % Replaceable Parts	40-50 % Replaceable Parts	30-40 % Replaceable Parts	20-30 % Replaceable Parts	10-20 % Replaceable Parts	0-10 % Replaceable Parts
Reliability	>5x Standard Stresses	5.0x Standard Stresses	4.5x Standard Stresses	4.0x Standard Stresses	3.5x Standard Stresses	3.0x Standard Stresses	2.5x Standard Stresses	2.0x Standard Stresses	1.5x Standard Stresses	1.0x Standard Stresses
Recyclability	90-100 % Recyclable Parts	80-90 % Recyclable Parts	70-80% Recyclable Parts	60-70 % Recyclable Parts	50-60 % Recyclable Parts	40-50 % Recyclable Parts	30-40 % Recyclable Parts	20-30 % Recyclable Parts	10-20 % Recyclable Parts	0-10 % Recyclable Parts
Composability	90-100 % Compostable Parts	80-90 % Compostable parts	70-80% Compostable parts	60-70 % Compostable parts	50-60 % Compostable parts	40-50 % Compostable parts	30-40 % Compostable parts	20-30 % Compostable parts	10-20 % Compostable parts	0-10 % Compostable parts

Table.4 *Qualitative Assessment Chart for Lamp, Table by Author*

(A) Cradle To Gate (Production)

Part	Quantity	Cost	Weight	kg CO2e/kg	Source	CO2e
A&M Beech	1	$24.00	5.097	0.3060	ICE	1.5597
H.F Beech	1	$20.74	3.775	0.3060	ICE	1.1552
Bolt/nut	2	$1.49	0.040	0.7948	CEDA (GQ)	0.0318
12v Plug	3	$26.61	0.022	0.5803	CEDA (IO)	0.0129
						0.0000
12v Jack	3	$16.32	0.020	0.5803	CEDA (IO)	0.0118
						0.0000
Socket	1	$2.20	0.007	0.4915	CEDA (JD)	0.0035
						0.0000
Bulb	1	$12.98	0.044	0.4915	CEDA (JD)	0.0215
						0.0000
Wire (ft)	20	$25.00	0.256	0.7815	CEDA (JQ)	0.2001
LED Driver	1	$39.00	0.490	0.4915	CEDA (JD)	0.2408
			0.490			0.0000
Plug	1	$2.50	0.012	0.7135	CEDA (JR)	0.0086
Switch	1	$4.46	0.022	0.7135	CEDA (JR)	0.0158
						0.0000
Potentiometer	1	$2.50	0.007	0.7135	CEDA (JR)	0.0048
Shade Frame	1	$2.49	0.115	4.5183	CEDA (FS)	0.5182
						0.0000
Total		$180.29	10.397	11.4821		3.78

Carbon Storage

Part	Quantity	Cost (Total)	Weight (Total)	kg CO2e/kg	Source	CO2e
Beech Total	1	$24.00	2.000	-1.5900	ICE	-3.1800
Total						-3.18

Table.5 *Cradle to Gate Phase Emissions for Lamp, Table by Author*

(B) Gate to Point of Sale (Transportation)

Part	Location A	Location B	MoT	Distance	CO2e/kg/km	Source	CO2e
A&M Beech	Germany	Cambridge ON	Road /Boat	6793.136	0.000024	McKinnon	0.8379
H.F Beech	Haliburton	Haliburton	NA	NA	NA	NA	
Bolt/nut	Hamilton	Montreal	Truck	540.000	0.000062	McKinnon	0.0013
12v Plug	Chicago	Thief River Falls	Truck	1149.259	0.000062	McKinnon	0.0016
							0.0000
12v Jack	Chicago	Thief River Falls	Truck	1149.259	0.000062	McKinnon	0.0015
							0.0000
Socket	China	Vancouver	Ship Container	10011.700	0.000008	McKinnon	0.0006
	Vancouver	Mississauga	Truck	4418.880	0.000062	McKinnon	0.0020
Bulb	China	Montreal	Ship Container	21854.084	0.000008	McKinnon	0.0077
	Montreal	Orangeville	Truck	816.795	0.000062	McKinnon	0.0022
Wire (ft)	Florence, MA	Florence, MA	NA	NA	NA	NA	
LED Driver	Suzhou	LA, CA	Ship Container	10243.000	0.000008	McKinnon	0.0402
	LA, CA	Thief River Falls	Truck	3035.720	0.000062	McKinnon	0.0922
Plug	Mexico	Florence, MA		4355.400	0.000062	McKinnon	0.0032
Switch	China	Vancouver	Ship Container	10011.700	0.000008	McKinnon	0.0018
	Vancouver	Mississauga	Truck	4418.880	0.000062	McKinnon	0.0061
Potentiometer	China	Vancouver	Ship Container	10011.700	0.000008	McKinnon	0.0005
	Vancouver	Mississauga	Truck	4418.880	0.000062	McKinnon	0.0018
Shade Frame	China	Vancouver	Ship Container	10011.700	0.000008	McKinnon	0.0092
	Vancouver	Mississauga	Truck	4418.880	0.000062	McKinnon	0.0314
Total				107658.97			1.04

Table.6 *Gate to Point of Sale Phase Emissions for Lamp, Table by Author*

(C) Point of Sale to Site (Transportation)

Part	Location B	Location C	MoT	Distance	CO2e/kg/km	Source	kgCO2e2
A&M Beech	Cambridge ON	Minden	Truck			McKinnon	0.0000
H.F Beech	Haliburton	Minden	Car	53.970	0.192000	OWIN	1.0362
Bolt/nut	Montreal	Minden	Truck	800.296	0.000062	McKinnon	0.0020
12v Plug	Thief River Falls	Minden	Truck	466.404	0.000062	McKinnon	0.0006
	Winnipeg	Minden	Plane	1505.300	0.000602	McKinnon	0.0201
12v Jack	Thief River Falls	Minden	Truck	466.404	0.000062	McKinnon	0.0006
	Winnipeg	Minden	Plane	1505.300	0.000602	McKinnon	0.0185
Socket	Orangeville	Minden	Truck	199.000	0.000602	McKinnon	0.0009
							0.0000
Bulb	Orangeville	Minden	Truck	1275.277	0.000062	McKinnon	0.0035
							0.0000
Wire (ft)	Florence, MA	Minden	Truck	1276.277	0.000062	McKinnon	0.0203
LED Driver	Thief River Falls	Minden	Truck	466.404	0.000062	McKinnon	0.0142
	Winnipeg	Minden	Plane	1505.300	0.000602	McKinnon	0.4440
Plug	Mexico	Minden	Truck	1276.277	0.000062	McKinnon	0.0009
Switch	Mississauga	Minden	Truck	241.000	0.000062	McKinnon	0.0003
							0.0000
Potentiometer	Mississauga	Minden	Truck	241.000	0.000062	McKinnon	0.0001
							0.0000
Shade Frame	Orangeville	Minden	Truck	199.000	0.000602	McKinnon	0.0137
Total				11477.21			1.58

Table.7 *Point of Sale to Site Phase Emissions for Bed, Table by Author*

(D) Construction

Task	Hours	kw of tool	kg CO2e/kwh	kgCO2e
Steaming	2	1.5	0.031	0.093
Cutting	1	1.8	0.031	0.0558
Planing	1	1.8	0.031	0.0558
Soldering	1	0.02	0.031	0.00062
Total				0.20522

(E) Operation

Hours / Year	kw of tool	kg CO2e/kg	CO2e
365	0.005	0.031	0.000155
Total			0.000155

(F) End of Life

Landfill Transportation

Product	Weight	MoT	Distance*	CO2e/kg/km	Source	Co2e
Lamp	2.32	Truck	50	0.000062	McKinnon	0.007192

Landfill Processing

Product	Weight	kg CO2e / kg	Source	CO2e
Lamp	2.32	1.152	Jeffery Morris	2.6726

Recycling Transportation

Product	Weight	MoT	Distance*	CO2e/kg/km	Source	Co2e
Lamp	2.32	Truck	250	0.000062	McKinnon	0.03596

Mixed Recycling Processing

Product	Weight	kg CO2e / kg	Source	CO2e
Lamp	2.32	0.824	Jeffery Morris	1.9117

Table.8 *Construction, Operation, and End-of-Life Phase Emissions for Bed, Table by Author*

Built Photos

Figure.57 *Lamp Perspective Angle A, Photo By Author*

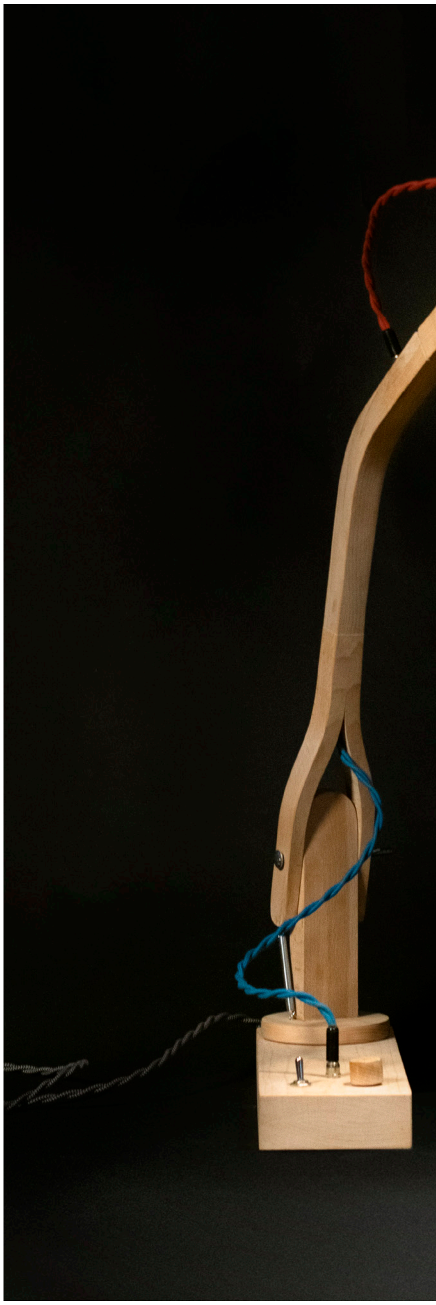
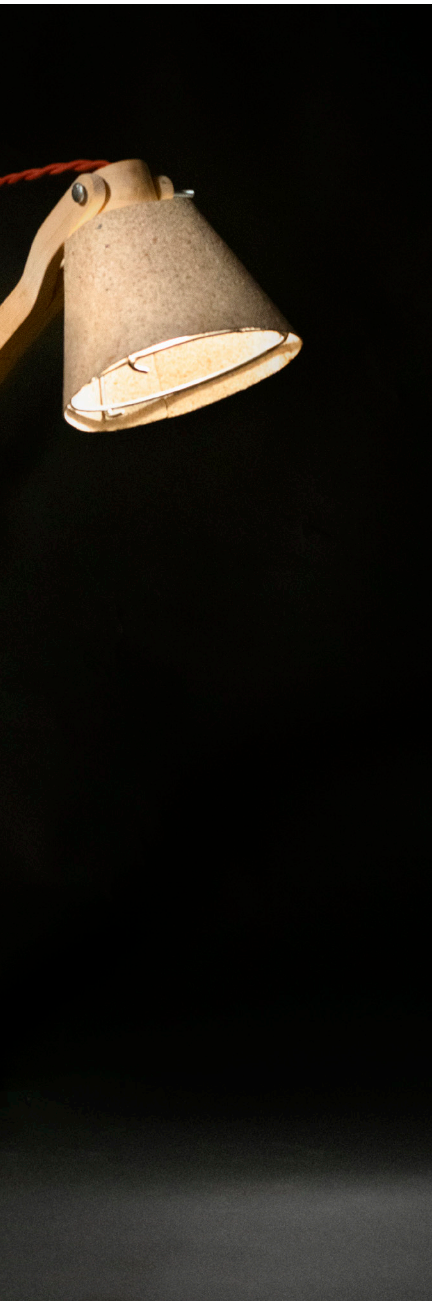


Figure.58 *Lamp Perspective Angle B, Ph*



oto By Author

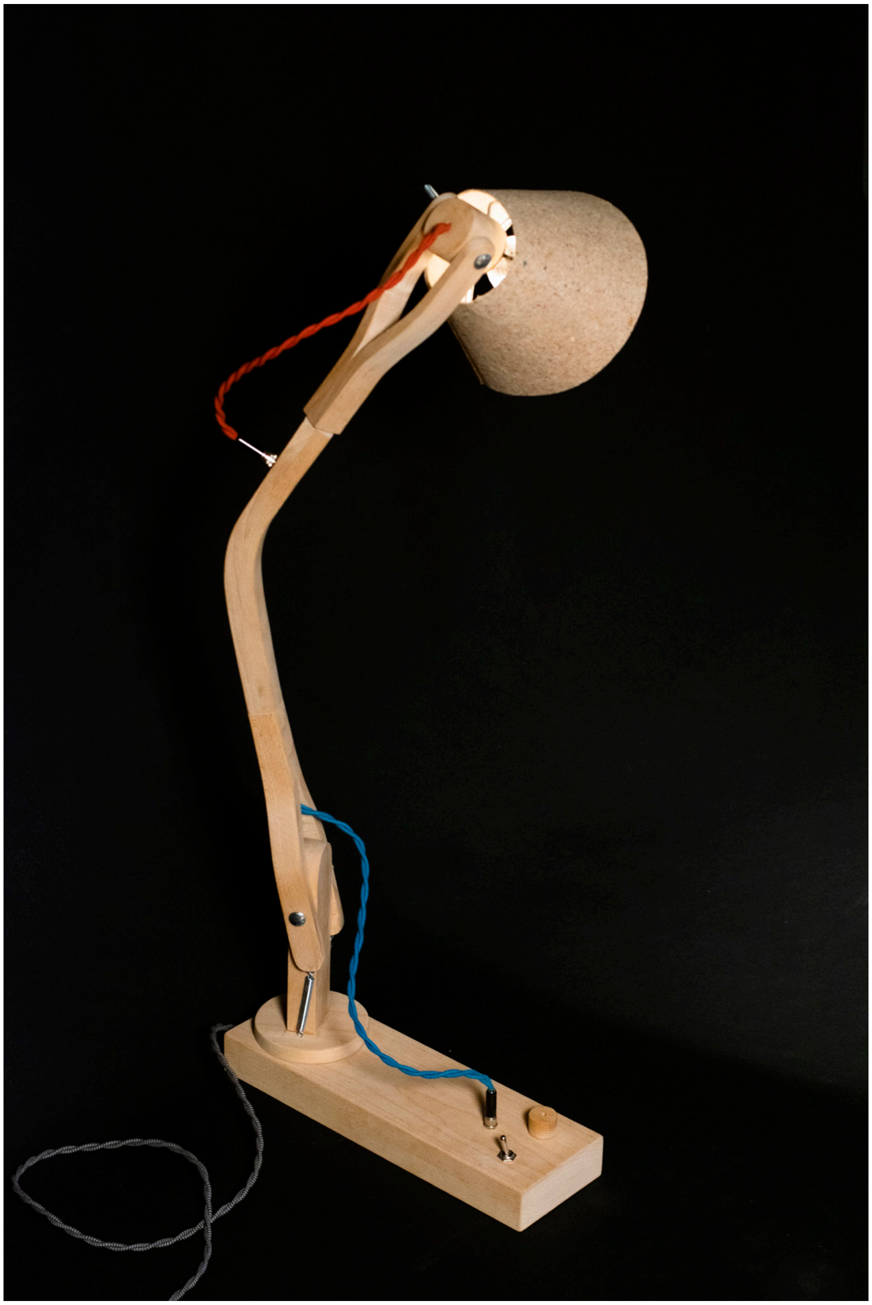


Figure.59 *Lamp Perspective Angle C, Photo By Author*

Figure.60 *Lamp Side Profile, Photo By Author*

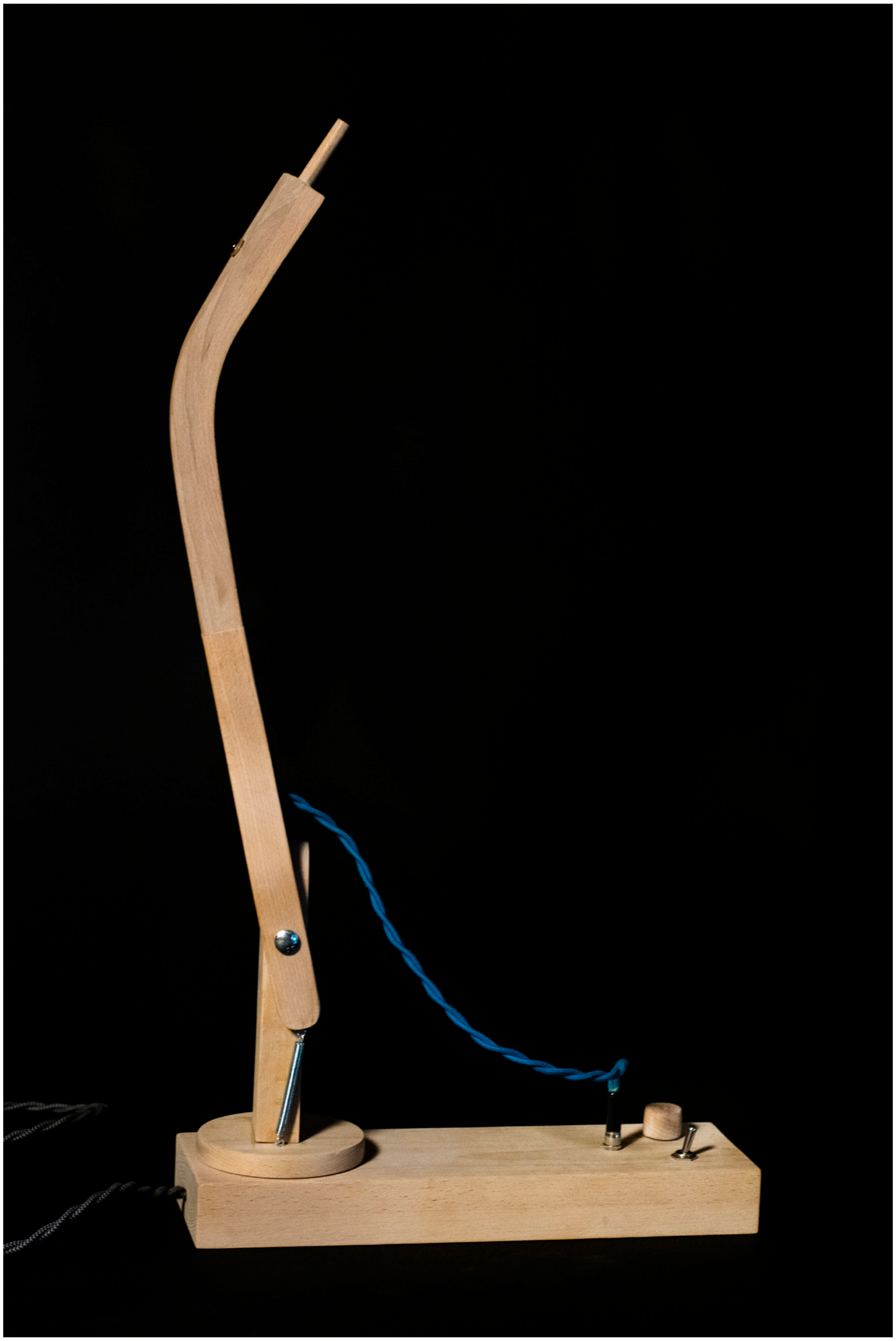


Figure.61 *Lamp with Head Removed, Photo By Author*

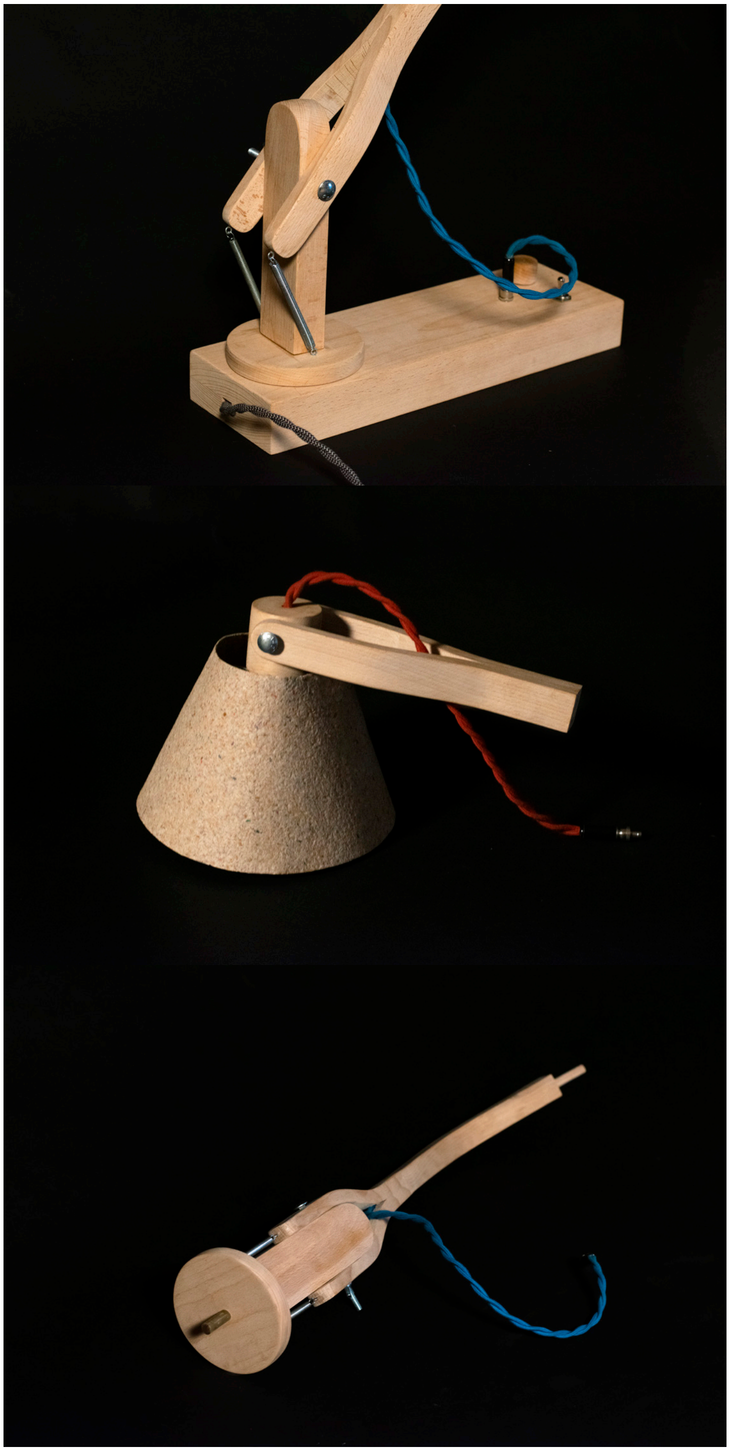


Figure.62 *Lamp Parts Separated, Photos By Author*

Desk

4.

Section Contents

Illustration.12 *Original Rendering of the Desk, Visualisation by Author*

“A desk is a dangerous place from which to view the world.”

John le Carré

Chapter 4 – Desk Case Study

“A desk is a dangerous place from which to view the world.” (Le Carré, 1978) John le Carré wrote in his fictional espionage novel *The Honourable Schoolboy.* His real-world career in MI5 and MI6 inspired his writing. The quotation is included here as a reminder to the architect that when designing at our desks, confined to trace paper or software, we can become blind to the real-world consequences of our imaginations.

Artefact Description

The ambition behind the desk was to create a universal table that could be used as a small dining table, a coffee table, or (most likely) a desk. Most of the design efforts were focused on the legs. If the legs were made to be adjustable, it would allow the tabletop to be changeable. The adaptable legs could support a larger or smaller surface depending on the user’s needs. Furthermore, the modular nature of the design would encourage easy repairs and upgrades to the table. The height of the table adjusts using a leg system that raises and lowers; the legs are comprised of two mirrored “U” shaped bends connected by two vertical elements. These vertical elements allow the desk to raise and lower from 650mm to 850mm. A third leg is attached to the lower portion of the system, creating a tripod that improves lateral stability. The tripod leg can be installed on the inward or outward side of the main leg. The goal was for the tabletop to freely rest upon the two tripod leg systems without the need for permanent fastening.

However, in the final prototype, threaded inserts secured the tripods to the table with one stretcher connected to them (see *Construction Process*). While the final design favours the desk configuration, its modular design creates a versatile product able to serve future uses.

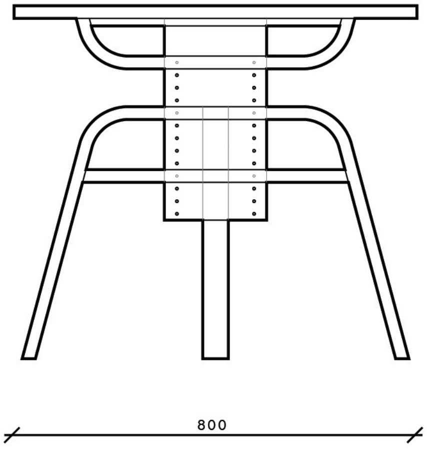


Illustration.13 *Desk Side Elevation, Drawing by Author*

Orthographic Drawings

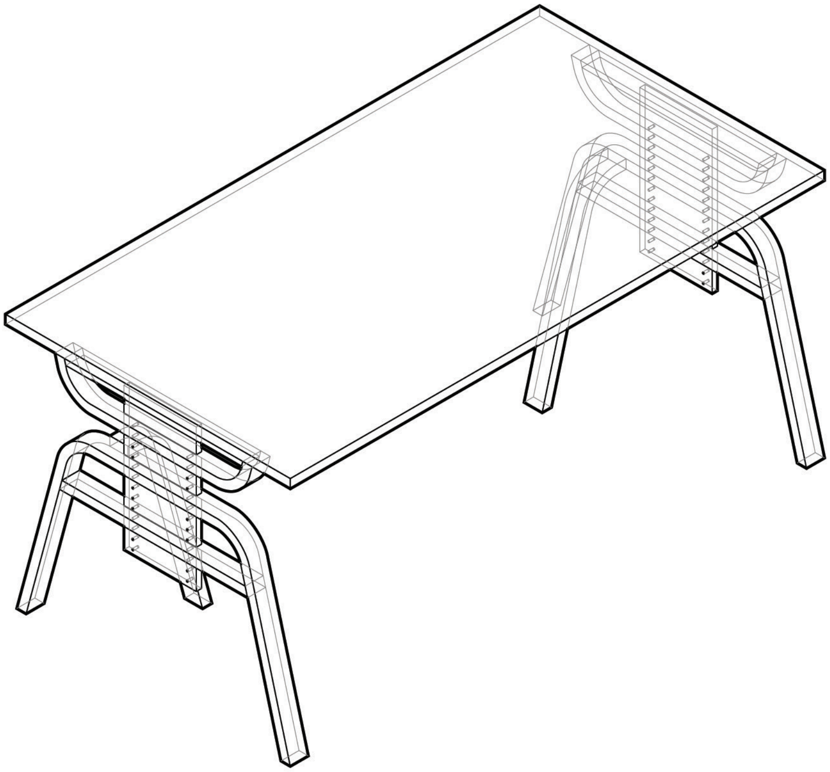


Illustration.14 *Desk Axonometric, Drawing by Author*

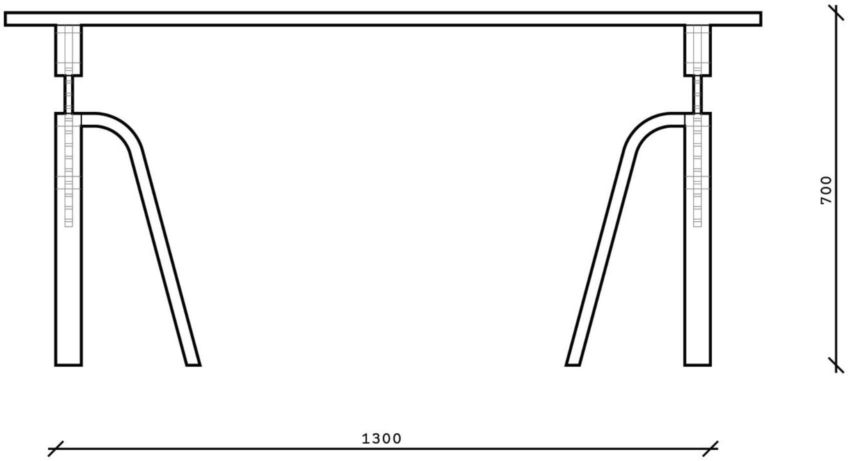


Illustration.15 *Desk Front Elevation, Drawing By Author*

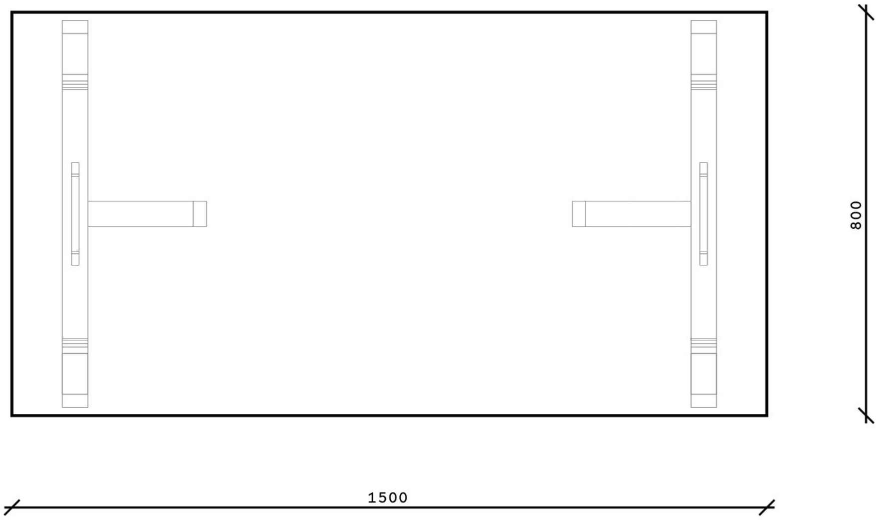


Illustration.16 *Desk Plan, Drawign By Author*

Figure.63 *Desk Supply Chain Map - North American Scale, Map by Author*

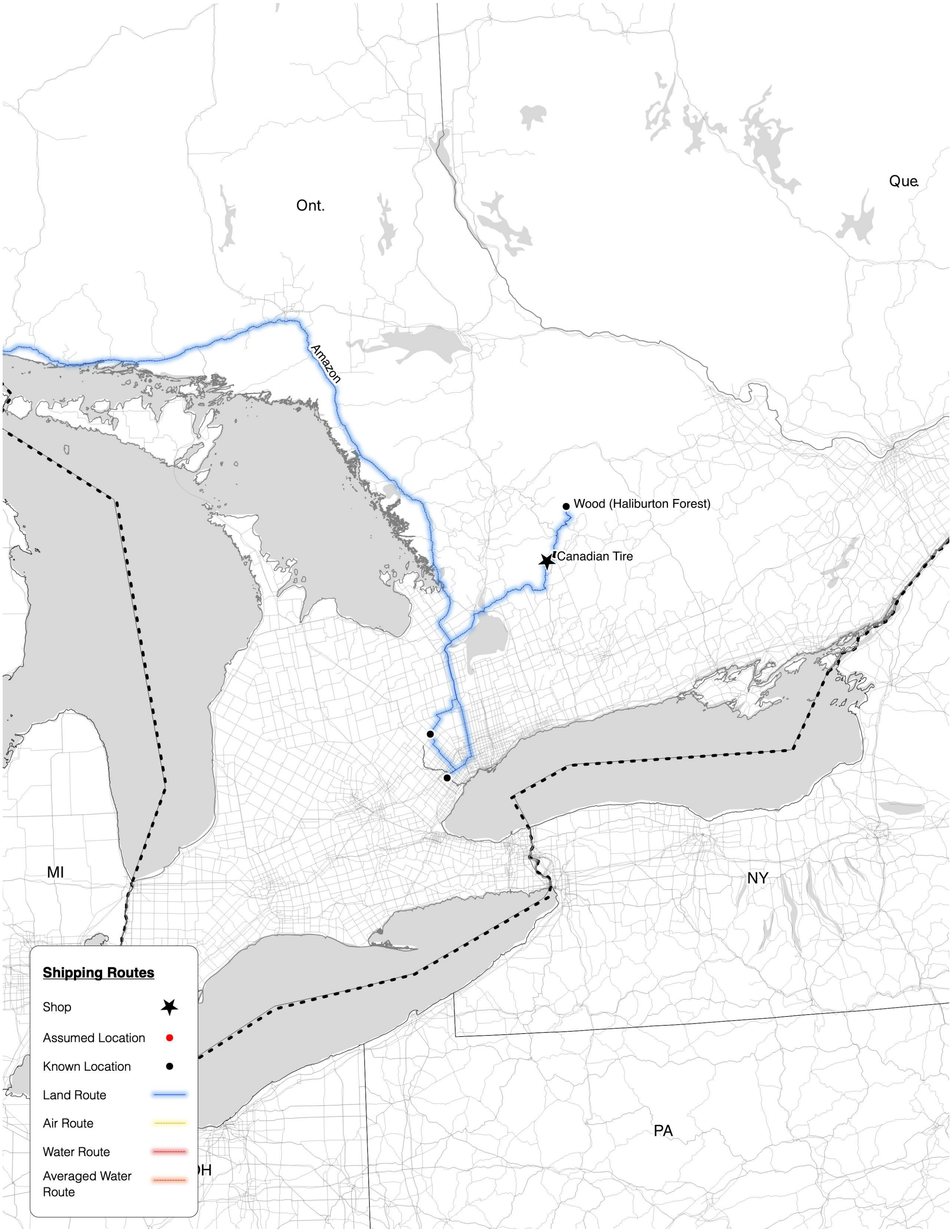


Figure.64 *Desk Supply Chain Map - Provincial Scale, Map by Author*

Desk Parts Catalogue

Figure.65 *Desk Table Top, Photo By Author*

Figure.66 *Desk Tripod Leg, Photo By Author*

Figure.67 *Desk Table Top, Photo By Author*

Figure.68 *Desk Table Top, Photo By Author*

Figure.69 *Assembled Desk Leg - Lowered Position, Photo By Author*

Figure.70 *Assembled Desk Leg - Raised Position, Photo By Author*

Construction Process

Tabletop

The tabletop was constructed first. Boards of ash wood were planed and arranged. Biscuits were inserted into the edges of the boards to align them, followed by glue and clamping pressure. Aprons were attached at each end of the desk running from front to back. One apron running left to right was added later for stability. Once the glue dried, the assembled panel was hand planed and finely sanded.

Legs

Six pieces of timber were steamed in batches of two to create the legs. Each leg consists of two "U" shaped bends that are mirrored and connected by two vertical members. The vertical members slide through the two bent pieces with a horizontal brace included allowing the desk height to be adjusted. The bent pieces were all created on the same form; a 90-degree bend with a radius of 75mm. After spring back, the angle of the bends becomes approximately 105 degrees. Once pieces cooled, they were unrestrained and left to dry. The finished bends needed a fair amount of sanding; it was typical for the fibres that were in tension at the outer corners of the bend to tear, while the inner corners that would experience compression tended to crinkle. These imperfections were sanded out but likely contributed to future close-in *(*where the wood dries and contracts, tightening the angle of the bend).

Figure.71 *Biscuit, Photo by Author*

Figure.72 *Biscuit Hole, Photo by Author*

Figure.73 *Desk Aprons, Photo by Author*

Figure.74 *Hand Planning the Tabletop, Photos by Author*

Figure.75 *a) Rough Cut Ash. b) Planed Ash, Photo by Author*

Figure.76 *Initial Desk Assembly, Photo by Author*

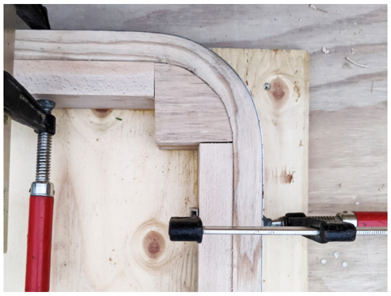


Figure.77 *Desk Leg in Bending Mould, Photo by Author*

Figure.78 *Drying Bent Wood, Photo by Author*

Figure.79 *Initial Desk Assembly, Photo by Author*

Figure.80 *Brushing on White Wash, Photo By Author*

Figure.81 *Buffing off White Wash, Photo By Author*

Figure.82 *Completed Desk-top Finish, Photo By Author*

Figure.83 *Applying a Natural Top Coat, Photo By Author*

Finishing and Staining

The desk legs included complex curves and joinery that made applying finish to the final piece complex. It was the first piece of furniture that finish was applied to, and while the flat tabletop had minor issues, the nooks of the legs proved to be challenging. A light natural look to the wood was the preference. Therefore, a pickling stain was chosen to whitewash the wood and counteract a clear topcoat's darkening or yellowing effects. Applying the whitewash to the assembled desk caused blotting in the corners and on the legs. The desk needed to be disassembled, and the stain was sanded off. In the future, staining individual components before assembly would produce a superior result. A can of locally available water-based stain was initially used, but the stain was no longer in stock upon returning to get more. In the interest of time, a penetrating oil stain was purchased. This stain did apply more evenly and achieved a subtle lightening effect, accentuating the porous wood grain. Unfortunately, oil stains are a petroleum-based product with higher levels of volatile organic compounds (VOCs), which are toxic to both people and the environment. A Danish Soap Finish would accomplish slight protection and brightening of the wood in future projects. One drawback is that it would need to be reapplied over time. The product used for the topcoat was a combination of beeswax and linseed oil. While it took an extended amount of time to dry and build up layers, the experience of using a non-toxic product was greatly preferred for both the application process and eventually the end-of-life disposal.

Figure.84 *Desk Leg on Bending Form, Photo By Author*

Figure.86 *Drilling Holes for Sliding desk Component, Photo By Author*

Figure.85 *Completed Drilling Sliding desk Component, Photo By Author*

Figure.87 *Chiseling Holes into a Rectangular Shape, Photo By Author*

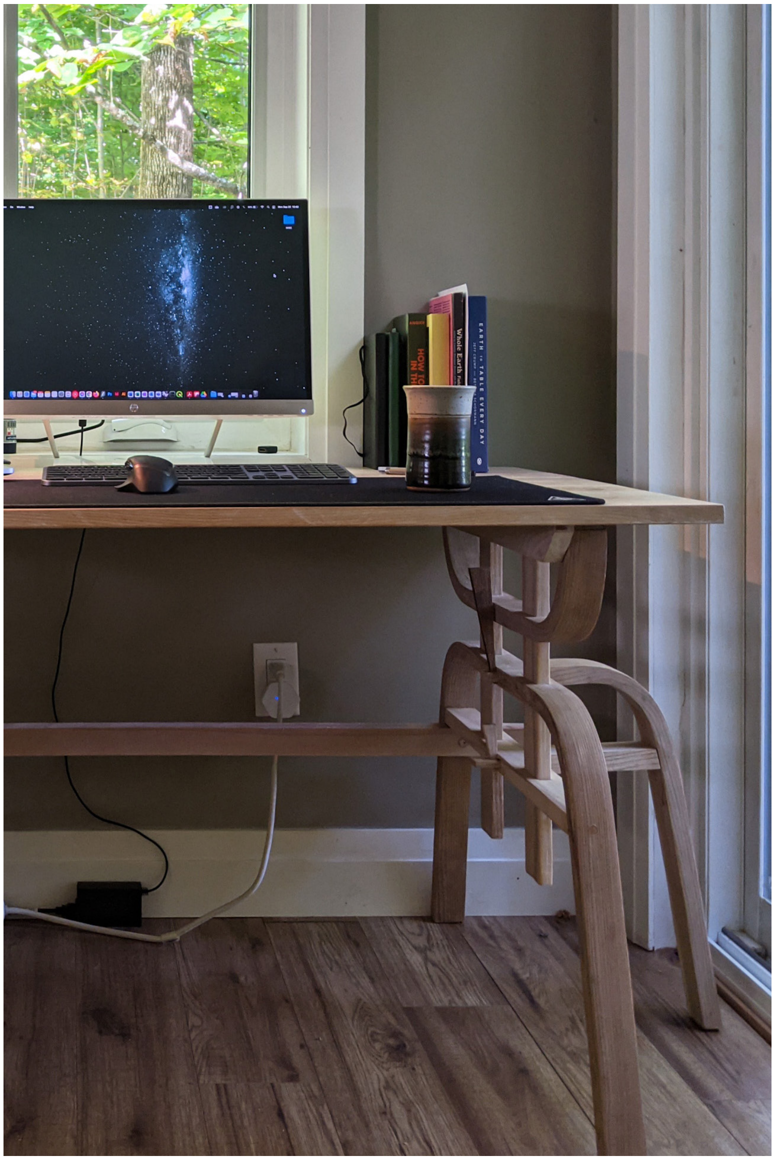


Figure.88 *Desk in Use, Photo by Author*

Final Assembly

The openings that were mortised out of the legs were a tight fit, and often friction was enough to hold the desk at the correct height. Though it can be challenging to raise the height of the desk, the stability of the tight fit was not compromised for better sliding pieces. Bolts and wingnuts were included to lock the desk at a chosen height. The original intention of the legs was to have the tabletop simply rest on the tripod legs, but once assembled, the stability of the desk in the lateral direction was not adequate. This led to a series of additions to strengthen the desk.

- The inclusion of an apron under the tabletop and a brace halfway down the legs
- The third leg of the tripods received a support bar one-third of the way down
- Threaded inserts were added to the tabletop so the legs could be fastened to it and still be removed.

The desk, now sufficiently solid, still accomplishes the desired objective of adaptability despite needing to remove some bolts before changing out components.

Carbon Label & Calculations

Carbon Facts

Item: Desk

Weight (kg)	22.92	kg
Emissions / kg	0.42	CO$_2$e/kg
Total Emissions	46.06	kgCO$_2$e
Inc. Carbon Storage	9.61	kgCO$_2$e
% Yearly Value*	0.20%	
Production	15.920	kgCO$_2$e
Transportation	7.277	kgCO$_2$e
End-of-life	22.858	kgCO$_2$e
Operation (Yearly)	0.000	kgCO$_2$e
Carbon Storage	-36.443	kgCO$_2$e

Lifespan Facts

Lifespan Goal	75	years
Cost / Year	2.678	$/yr
Adaptability	Good	
Maintainability	Excellent	
Reliability	Fair	
Rcycable Parts	Excellent	
Biodegradable Parts	Excellent	

Certifications

Sustainable Forestry	✓
Fair Trade	✓
Safe Workplace	✓

Ingredients

Ash Wood, Steel, PVA Glue

Table.9 *Desk Carbon Label, Table by Author*

Discussion & Analysis

Observation on the process of making

The desk included the first components to use the green lumber in bending. It was remarkable to see a length of wood with a cross-section of 1” x 2” (2.54cm x 5.08cm) bend a full 90 degrees; something that would have been impossible an hour before the wood was steamed. After much frustration trying to bend drier wood, the freshly cut green ash bent beautifully. Using green lumber made it possible for none of the pieces to fail in bending. Failure only happened if there were knots or other weak points near the bending corner. With flat sawn wood, the grain direction would vary across pieces, and therefore some pieces bent better than others. It was noted that pieces with a wide grain run-out performed better with the flatsawn face parallel and the vertical grain perpendicular to the bending mould. When a tight vertical grain faced the bending mould (from a rift sawn cut), it had a greater tendency to crinkle on the inner face. On the other hand, if the grain run-out on a flat sawn piece is too frequent, it risks splitting the wood.

Applying finish to woodwork is often challenging; stains, oils, and polymer coatings exaggerate any wood’s imperfections. In a professional setting, finishes may be sprayed on, but brushes and cloths were used for this project. Sanding many curved pieces to achieve a smooth surface took more time than expected. Properly sanded components and the careful application of finish had a positive contribution to the final product’s appearance. It is essential to wait the appropriate amount of time for finishes to dry, and the natural finishes take much longer to dry. Rushing this process resulted in re-sanding and re-applying finish. It is evident that environmentally conscious materials and processes take more time to implement, making it safe to assume that this increases costs and deters commercial companies.

Observations on the Data

The desk had far fewer material sources than the lamp and the chair. The wood, bolts, and threaded inserts already had existing data entered in the spreadsheet, which allowed for the quick adjustment of quantities or weights before outputting the label. The initial investment in creating a system to sum emissions, distances, and costs, pays off once supply chains are established. If a company consistently uses similar suppliers, it becomes easy to create a label for a new product. There is merit in taking the time to design with material and supplier in mind.

End-of-life Emissions and Carbon Storage are two sets of data that should be read in tandem. The quantity of wood in the desk makes its overall emissions lower thanks to carbon sequestration of -36.443 kgCO2e. However, at the end of the desk's life, its weight in CO2e (22.92kg) is released from recycling and decay in a landfill. The label assumes that half the weight of the item is recycled, and half is landfilled.

Shipping and transportation for the desk materials were predominantly local, totalling 7.277 KgCO2e. The threaded inserts ordered online were produced in China. The rest of the materials were produced within Ontario. The desk's restrained set of materials made it easier to use a localised supply chain.

Going forward, timber production will be the most outstanding individual contribution to early-stage emissions in primarily wood designs. Knowing the carbon emissions of the primary material of a project is a good area to focus design efforts, ensuring one finds a quality supplier or investigates a better alternative material.

Emission Goals: Canada & Global

i

Canada pop	37590000	**World Pop**	7800000000
2030 Goal (Mt)	438	**2030 Goal (Gt)**	40
Kg	438000000000	**Kg**	40300000000000
Per Person	11652	**Per Person**	5167

ii ***Product: Desk***

Total Cost	200.85	**A Co2e**	Cradle To Gate (Production)	15.92
Total Weight	49.81	**B Co2e**	Gate to Point of Sale (Transportation)	0.02
Built Weight	22.92	**C Co2e**	Point of Sale to Site (Transportation)	7.25
Total Co2e	23.20	**D Co2e**	Construction	0.571
Stored Carbon	-36.44	**E Co2e**	Operation	0.00
		F Co2e	End of Life	22.86
		G Co2e	Carbon Storage	-36.4428

Table.10 *Summery of Data for Desk, Table by Author*

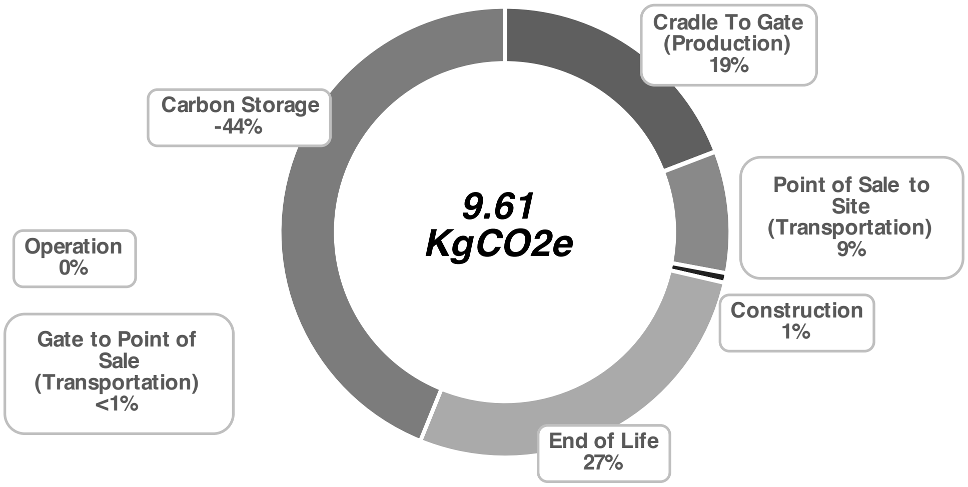


Table.11 *Desk Emission Phase Breakdown*

	Excellent		Very Good		Good		Fair		Poor	
	10	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Adaptability	5+ Adaptable Uses	\	4 Adaptable uses	\	3 Adaptable Uses	\	2 Adaptable Uses	\	1 Adaptable Use	\
Maintainability	90-100 % Replaceable Parts	80-90 % Replaceable Parts	70-80% Replaceable Parts	60-70 % Replaceable Parts	50-60 % Replaceable Parts	40-50 % Replaceable Parts	30-40 % Replaceable Parts	20-30 % Replaceable Parts	10-20 % Replaceable Parts	0-10 % Replaceable Parts
Reliability	>5x Standard Stresses	5.0x Standard Stresses	4.5x Standard Stresses	4.0x Standard Stresses	3.5x Standard Stresses	3.0x Standard Stresses	2.5x Standard Stresses	2.0x Standard Stresses	1.5x Standard Stresses	1.0x Standard Stresses
Recyclability	90-100 % Recyclable Parts	80-90 % Recyclable Parts	70-80% Recyclable Parts	60-70 % Recyclable Parts	50-60 % Recyclable Parts	40-50 % Recyclable Parts	30-40 % Recyclable Parts	20-30 % Recyclable Parts	10-20 % Recyclable Parts	0-10 % Recyclable Parts
Composability	90-100 % Compostable Parts	80-90 % Compostable parts	70-80% Compostable parts	60-70 % Compostable parts	50-60 % Compostable parts	40-50 % Compostable parts	30-40 % Compostable parts	20-30 % Compostable parts	10-20 % Compostable parts	0-10 % Compostable parts

Table.12 *Qualitative Assessment Chart for Bed, Table by Author*

(A) Cradle To Gate (Production)

Part	Quantity	Cost	*inc waste Weight*	kg CO2e/kg	Source	CO2e
H.F. Ash	7	$145.17	49.560	0.3060	ICE	15.1654
Furn. Bolt	10	$1.49	0.200	3.0648	ICE/CEDA (GQ)	0.6130
Thrd. Insert	6	$53.22	0.044	3.0648	ICE/CEDA (GQ)	0.1361
						0.0000
Screws	14	$0.98	0.002	3.0648		0.0060
Total		$200.85	49.806			15.92

Carbon Storage

Part	Quantity	Cost (Total)	Weight (Total)	kg CO2e/kg	Source	CO2e
Ash Total	1		22.920	-1.59	ICE	-36.4428
Total						-36.4428

Table.13 *Cradle to Gate Phase Emissions for Desk, Table by Author*

(B) Gate to Point of Sale (Transportation)

Part	Location A	Location B	MoT	Distance	CO2e/kg/km	Source	CO2e
H.F. Ash	Haliburton	Haliburton	NA	NA	NA	NA	NA
Furn. Bolt	Hamilton	Minden	Truck	540.000	0.000062	McKinnon	0.0067
Thrd. Insert	China	Vancover	Ship	10011.700	0.000008	McKinnon	0.0036
Thrd. Insert 02	Vancover	Mississagua	Truck	4418.880	0.000062	McKinnon	0.0122
Screws	Hamilton	Minden	Truck	540.000	0.000062	McKinnon	0.0001
Total				15510.580			0.02

Table.14 *Gate to Point of Sale Phase Emissions for Desk, Table by Author*

(C) Point of Sale to Site (Transportation)

Part	Location B	Location C	MoT	Distance	CO2e/kg/km	Source	kgCO2e2
H.F. Ash	Haliburton	Minden	Car	53.970	0.192000	OWIN	7.2536
Furn. Bolt	Minden	Minden	Truck	53.970	0.000062	McKinnon	0.0007
Thrd. Insert	Mississagua	Minden	Truck	241.000	0.000062	McKinnon	0.0007
Thrd. Insert 02							
Screws	Minden	Minden	Truck	53.970	0.000062	McKinnon	0.0000
Total				402.910			7.25

Table.15 *Point of Sale to Site Phase Emissions for Desk, Table by Author*

(D) Construction

Task	Hours	kw of tool	kg CO2e/kwh	kgCO2e
Steaming	6	1.5	0.031	0.279
Cutting	2.5	1.8	0.031	0.1395
Planing	2	1.8	0.031	0.1116
Sanding	4	0.33	0.031	0.04092
Total				0.57102

(E) Operation

Hours / Year	kw of tool	kg CO2e/kg	CO2e
NA	NA	NA	NA
Total			0

(F) End of Life

Landfil Transportation

Product	Weight	MoT	Distance*	CO2e/kg/km	Source	Co2e
Desk	22.92	Truck	50	0.000062	McKinnon	0.071052

Landfill Processing

Product	Weight	kg CO2e / kg	Source	CO2e
Desk	22.92	1.152	Jeffery Morris	26.4038

Recycling Transportation

Product	Weight	MoT	Distance*	CO2e/kg/km	Source	Co2e
Chair	22.92	Truck	250	0.000062	McKinnon	0.35526

Mixed Recycling Processing

Product	Weight	kg CO2e / kg	Source	CO2e
Chair	22.92	0.824	Jeffery Morris	18.8861

Table.16 *Construction, Operation, and End-of-Life Phase Emissions for Bed, Table by Author*

Built Photos

Figure.89 *Desk Perspective A, Photo By Author*

Figure.90 *Desk Front Elevation - Raised Position, Photo By Author*

Figure.91 *Desk Front Elevation - Lowered Position, Photo By Author*

Figure.92 *Desk Top Detail - Raised Position, Photo By Author*

Figure.93 *Desk -Leg Detail, Photo By Author*

Chair

5.

Section Contents

Illustration.17 *Original Rendering of the Chair, Visualisation by Author*

"For here Am I sitting in a tin can, Far above the world. Planet Earth is blue, And there's nothing I can do."

David Bowie

Chapter 5 – Chair Case Study

Space Oddity was recorded in 1969 (Bowie David, 1969) —a time electrified by the landing of people on the moon. The lyrics convey a loss of communication and a feeling of helplessness. These emotions persist in the first quarter of the 21st century, where, with the advent of commercial space travel, it can be interpreted that the world's wealthiest people have more interest in leaving the planet than investing in a livable future on it. In the face of climate change, it is easy to feel like there is not much the individual can do, but certainly, there is value in a collective effort. People have inhabited the Earth for a minuscule fraction of the planet's history and yet have had a considerable effect on the biosphere. While uncontrollable natural events have led to the demise of other precious species, we may well be the cause of our destruction if we sit by.

Artefact Description

Many well-known architects have tried their hand at chair design. The chair is a simple design challenge compared to a building, but it also requires aesthetic and structural thinking. The chair is often a means of exploring a design idea at a smaller scale, as seen in the work of Alvar Aalto. The chair can also be a way of introducing design work to the masses, as it did for Charles and Ray Eames. The chair designed for this project is assembled with reversible attachment methods to remain an adaptable, modular piece. Sofas and chairs are commonly thrown away because the fabric or foam is worn out. The carbon footprint of chairs can significantly increase when leathers, synthetic fabric, and polyurethane foams are used. Some of the carbon emission and end-of-life issues are addressed using natural fabrics and a foam containing a high percentage of soy oil. The fabric backing of the chair is secured to a curved backrest and can be removed by undoing a series of four snap buttons. The legs of the chair and the upper seat are built in two separate pieces, connected by furniture bolts. The detachable base allows the chair's legs to be changed out, which provides the option of transforming the type of chair.

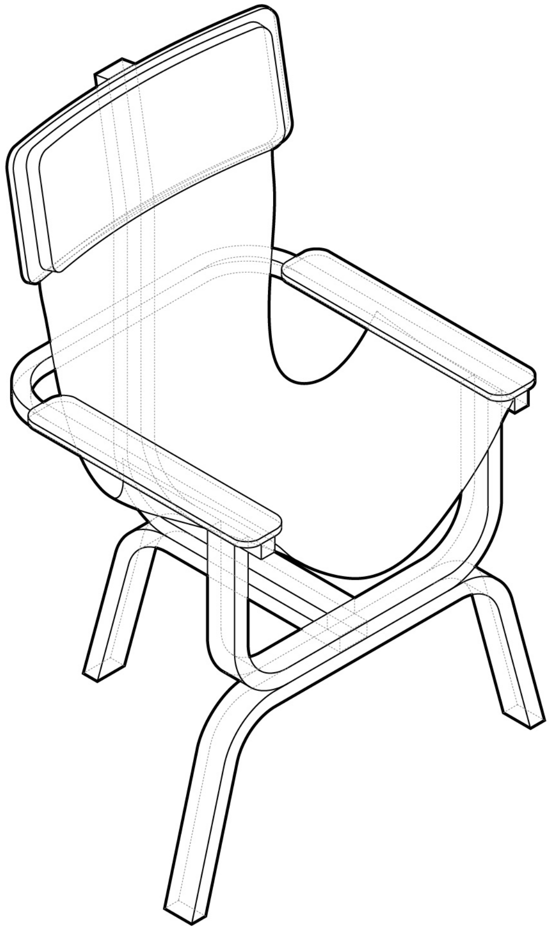


Illustration.18 *Original Axo of the Chair, Drawing by Author*

Original Design Orthographic Drawings

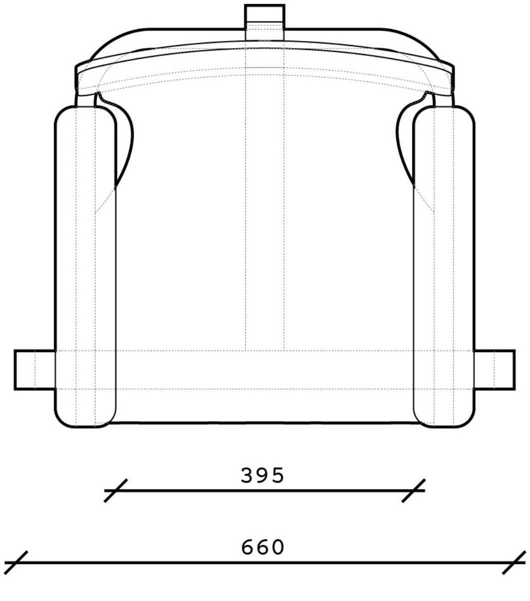


Illustration.19 *Original Plan of the Chair, Drawing by Author*

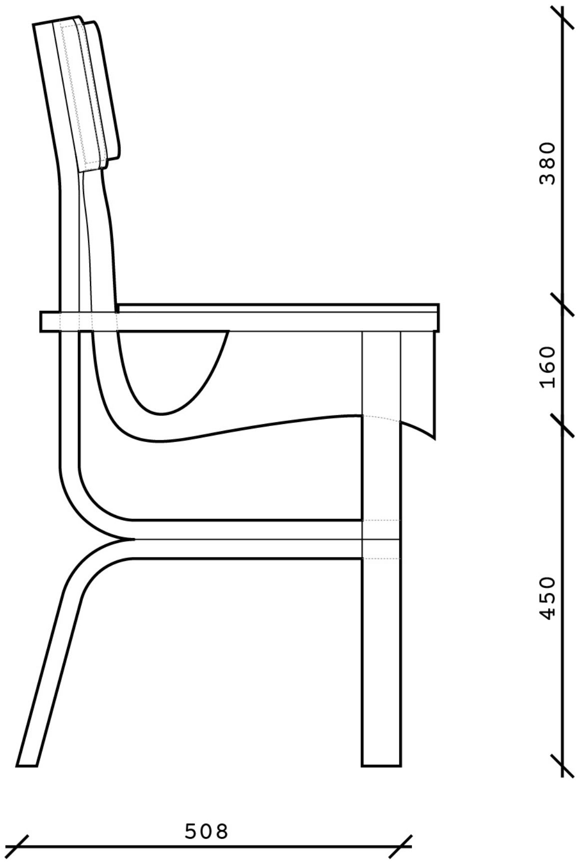


Illustration.21 *Original Side Elevation of the Chair, Drawing by Author*

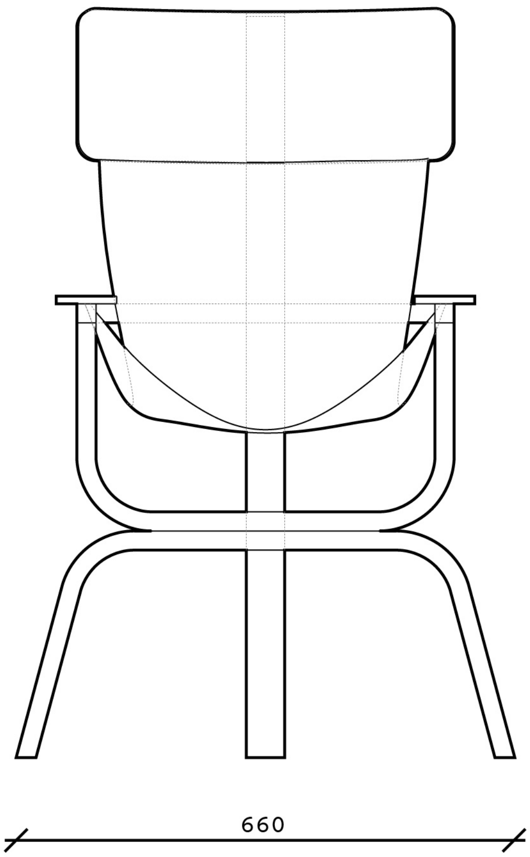
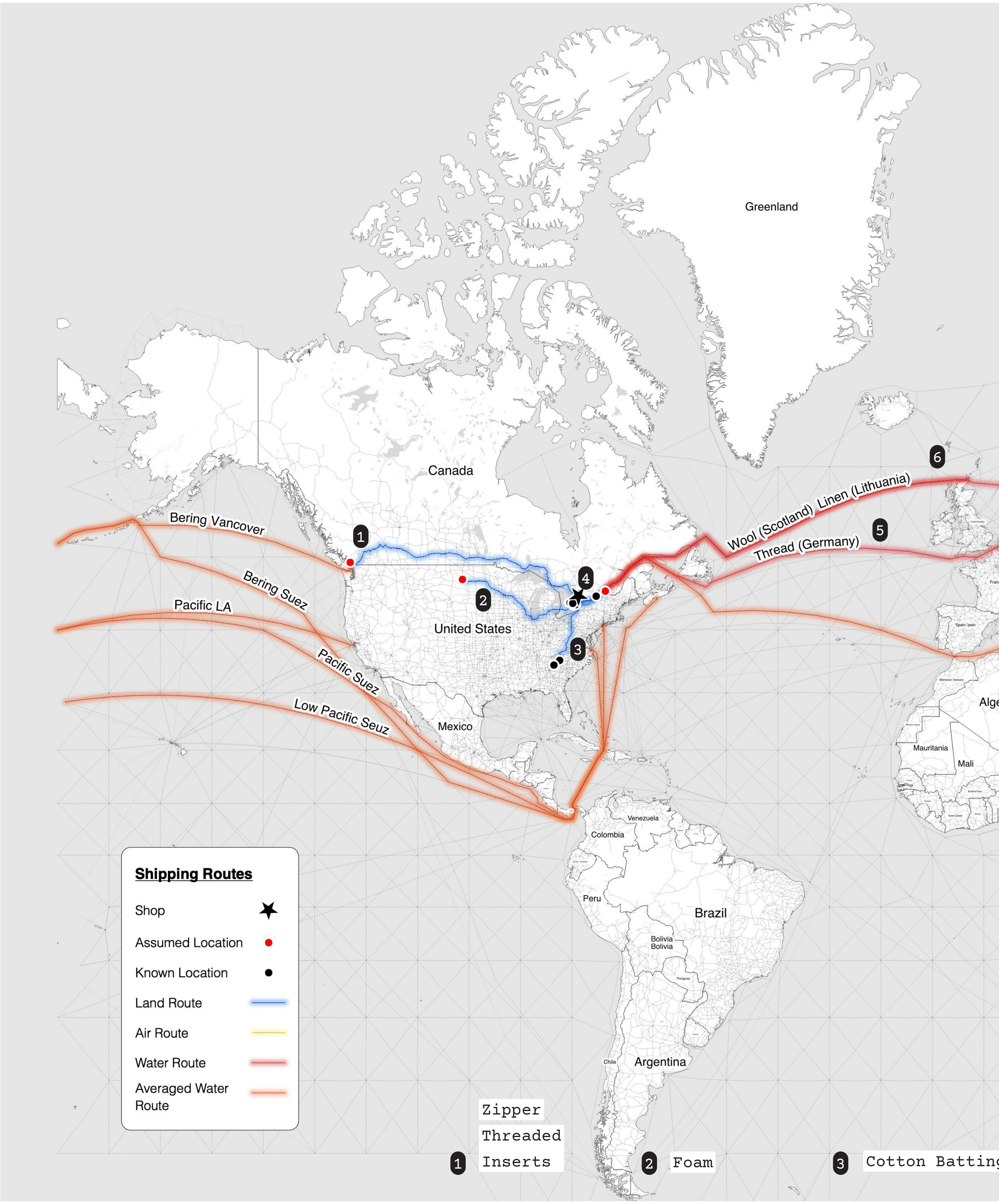


Illustration.23 *Original Side Elevation of the Chair, Drawing by Author*


Greenland
Canada
United States
Mexico
Venezuela
Colombia
Peru
Brazil
Bolivia
Argentina
Chile
Mauritania
Mali
Alge
Bering Vancouver
Bering Suez
Pacific LA
Pacific Suez
Low Pacific Seuz
Wool (Scotland)
Linen (Lithuania)
Thread (Germany)
1
2
3
4
5
6
Shipping Routes
Shop
Assumed Location
Known Location
Land Route
Air Route
Water Route
Averaged Water Route
1 Zipper Threaded Inserts
2 Foam
3 Cotton Batting

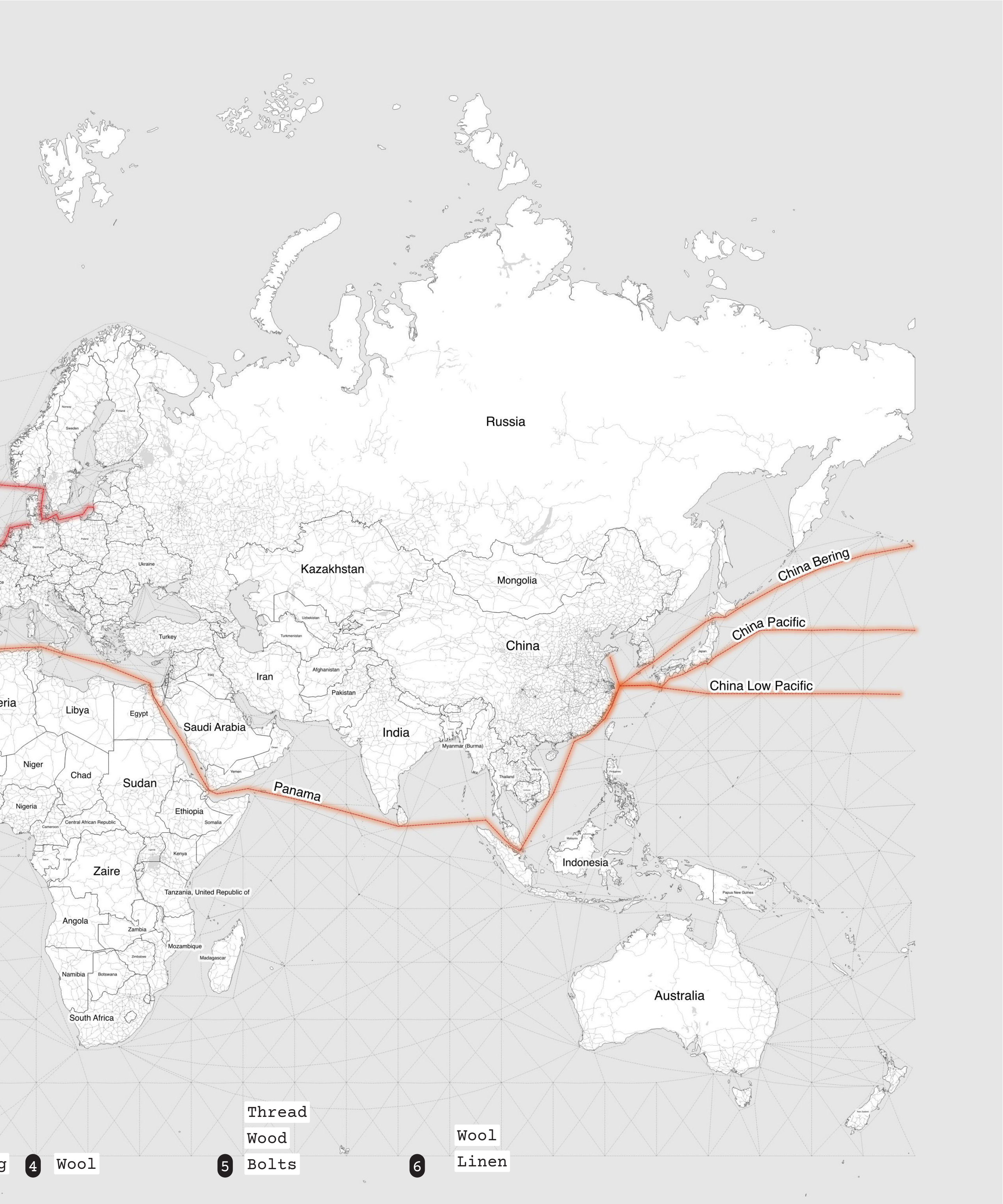

Russia
Kazakhstan
Mongolia
China
China Bering
China Pacific
China Low Pacific
Ukraine
Turkey
Uzbekistan
Turkmenistan
Iran
Afghanistan
Pakistan
India
Myanmar (Burma)
Thailand
Indonesia
Papua New Guinea
Australia
Libya
Egypt
Saudi Arabia
Yemen
Niger
Chad
Sudan
Nigeria
Ethiopia
Somalia
Central African Republic
Kenya
Zaire
Tanzania, United Republic of
Angola
Zambia
Mozambique
Madagascar
Namibia
Botswana
South Africa
Panama
4 Wool
5 Thread
Wood
Bolts
6 Wool
Linen

Figure.94 *Chair Supply Chain Map - North American Scale, Map by Author*

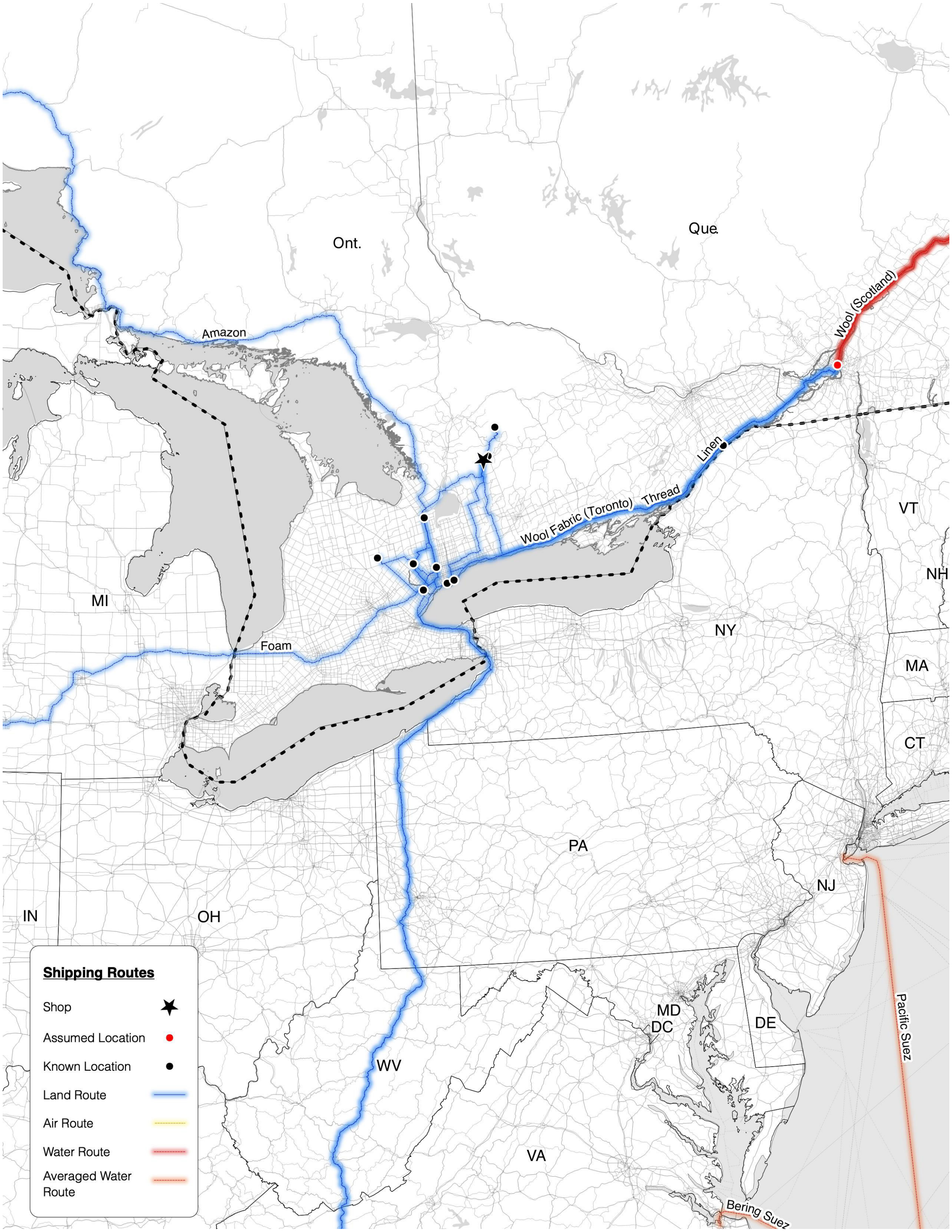


Figure.95 *Chair Supply Chain Map - Provincial Scale, Map by Author*

Figure.97 *Chair Back Connection Detail, Photo by Author*

Figure.98 *Chair Back Rest Detail, Photo by Author*

Figure.99 *Chair Arms, Photo by Author*

Figure.100 *Chair Underside, Photo by Author.*

Figure.96 *Chair Fame Original Assembly, Photo by Author*

Construction Process

The chair was the piece that experienced the most post-design changes. Compared to the other designs, the chair's success is far more tied to ergonomics. Even when working with standard proportions, it is challenging to predict how comfortable a chair will be until it is in use. Like all the pieces, the chair was indeed an experiment, and while it draws on designers like Aalto, Eames and Wegner, its novel design is subject to unpredictable material behaviours. The chair was relatively solid with all the components dry fitted together, but adjustments were needed to fine-tune the proportions and make the chair comfortable. The chair in the original design was somewhere between a lounge chair and an upright chair. The hybrid form made it confusing for a user, unsure if they should sit upright or lean back. The chair found a more natural form by temporarily strapping fabric, clamping on wood extensions, and propping up legs. It leaned towards functioning as a lounge chair; this meant the single back leg would be cut shorter to angle the chair backwards, the arms would be extended forward, and the seat deepened. The backrest felt best when it hit just below the shoulder blades, which was much lower than originally intended. The curved backrest became thinner in response to the challenges of bending a wide plank. The suspended fabric was replaced with a box cushion in the interest of strength and longevity. To have the hand-woven fabric be a weight-bearing element was too great of a risk. This decision resulted in the purchase of a piece of foam and the construction of a flat wooden seat.

The Frame

The chair was the third piece to be constructed, at which time the process of steam bending was becoming more familiar and, therefore, faster. The entire series of furniture was designed with the same angles and shapes to reuse the mould from one piece to another. While new forms were necessary for the few bends at a different angle, such as the 90-degree armrests, the form that made the desk legs was used to make the legs of the chair.

Figure.101 *Upper Canada Weaving Large Loom, Photo By Author*

Figure.102 *Upper Canada Weaving Filling Carrier, Photo By Author*

Figure.103 *Finished Woven Fabric, Photo by Author*

Figure.104 *Upper Canada Weaving Studio, Photo By Author*

One "U" shaped piece with two 75-degree bends, and one "L" shaped piece with a 75-degree bend, made up the tripod base of the chair. A mortise in the centre of the "U" bend received a tenon on the "L" shaped bend. A double-curved piece following the shape of the human spine and two more "U" shapes interlocking at 90 degrees made a frame for the body that sat on the tripod base. A thin curved backrest was bolted to the top of the chair, and flat armrests were attached to complete the frame.

The Fabric

The original design saw a three-dimensional piece of fabric give the chair a shape that followed the form of a sitting body. The fabric was to be suspended from the two arms and the backrest. This chair style is called a sling chair and can produce a comfortable seat without the use of foam. A loop would have been created at the top and sides of the fabric to attach it to the backrest and arms. This type of slide-on-attachment makes the fabric seat remain separate from the chair, allowing easy removal to wash, repair, or replace the fabric.

Once the chair's frame was built and the fabric arrived, it was decided that a more robust seat would be more functional and increase the piece's longevity. There was concern that the armrests and the fabric would not be suitable for long-term load-bearing components. The existing tripod base was changed to include a wooden seat topped with a cushion. On the backrest, the piece of fabric initially looped around the top of the chair would now terminate at the back of the cushion.

The fabric backrest is comprised of three layers: the front is a wool weave, the centre has cotton batting to provide some thickness, and the back is a linen fabric. Recycled polyester upholstery thread ensured strong seams. The box cushion used wool for the top and sides, again opting for the less expensive and tighter woven linen on the bottom. Zippers were sewn into the backrest and the cushion to aid the eventual replacement of the batting and foam over time. Snap buttons secure

Figure.105 *Sewing Box Cushion, Photo by Author*

Figure.106 *Finished Zipper, Photo by Author*

Figure.107 *Punching Hole For Button, Photo by Author*

Figure.108 *Finished Button, Photo by Author*

Figure.110 *Wool Fabric Cushion Corner, Photo By Author*

Figure.109 *Koosh Natural Foam, Photo by Author*

the fabric to the backrest. The easy removal makes it simple to wash. Each component was specifically chosen to test different fibres. Wool, linen, cotton, and polyester make up a large portion of the fabrics people use. Except for the thread, natural fibres were chosen for the chair due to the risks synthetic fabrics pose in creating micro-plastic and chemical effluents (Muthu, 2014). However, not all fibres are created equal; for example, cotton has a lower environmental impact than polyester but is considered to have lower ecological sustainability (Muthu, 2014). The book *Assessing the Environmental Impact of Textiles and the Clothing Supply Chain* is referenced when deciding what fabrics to source. The text also acknowledges the challenges of comparison in LCA and the need for more data (Muthu, 2014)

The wool fabric that makes up much of the upholstery was exceptional. It was handmade on a loom in Toronto by the founder of a small business called Upper Canada Weaving. The wool was spun in the 1960s and came from Scotland. This project was more concerned with process than pattern or colour, so the vintage yarn made a good candidate for the chair. A trip was made to visit both the maker and the loom in the attic workshop where the fabric was woven

Foam

After deciding to incorporate foam into the design, it became key to source a product that limited the petrochemicals needed to make standard polyurethane foam. Three alternatives were available: latex, down feathers, and soy-based foam. Latex was not readily available in custom sizes. Down was out of the budget for the chair. Therefore, the soy-based foam was the best option. The company Foamite sells a product called "Koosh Natural", advertised as being "made with soybean oil to replace most of the petrochemicals commonly used in the production of flexible polyurethane foam". It is assumed that "mostly soybean oil" could indicate a value from 51-99 per cent. Because the product still contains some petrochemicals, it is seen as a compromise that may complicate end-of-life disposal.

Carbon Label & Calculations

Carbon Facts

Item: Chair

Weight (kg)	13.8	kg
Emissions / kg	1.87	CO$_2$e/kg
Total Emissions	25.82	kgCO$_2$e
Inc. Carbon Storage	8.83	kgCO$_2$e
% Yearly Value*	0.00%	
Production	9.452	kgCO$_2$e
Transportation	2.600	kgCO$_2$e
End-of-life	13.763	kgCO$_2$e
Operation (Yearly)	0.000	kgCO$_2$e
Carbon Storage	-16.981	kgCO$_2$e

Lifespan Facts

Lifespan Goal	75	years
Cost / Year	6.0727	$/yr
Adaptability	Fair	
Maintainability	Excellent	
Reliability	Good	
Recyclable Parts	Excellent	
Biodegradable Parts	Excellent	

Certifications

Sustainable Forestry	✓
Fair Trade	✓
Safe Workplace	✓

Ingredients

Ash Wood, Steel, Nylon Zipper, Wool, Cotton, Polyester

Table.17 Chair Carbon Facts Sheet

Discussion & Analysis

Observation on the process of making

The now-familiar process of steam bending allowed the chair to be produced faster; however, quick production led to unexpected challenges later in the process. The pieces for the chair were brought indoors post-bending because the weather began to get colder. The drier environment, along with other variables, including the initial moisture content of the wood and the amount of compressive force during bending, resulted in something called close-in. Close-in is the opposite of spring-back. It is when the bent wood contracts and continues to bend during drying. Close-in likely could have been prevented if the freshly bent pieces of wood were allowed to stay on a drying mould for a long time. This project, like most, had deadlines to meet. Though ideal for the overall process, constructing drying moulds and waiting for the wood to reach a stable moisture content would have greatly extended the project timeline. The wood that experienced close-in was able to be slightly unbent by reintroducing moisture with a humidifier.

The chair's design exacerbated the inaccuracies of steam bending. It is difficult to predict the precise final angle of the bend, and it would be advantageous to have a design that incorporated a component that fixed bent pieces in their position. However, the chair had parts where one bend connected to another. These areas, while still strong, were more susceptible to movement. After all, wood is an organic material that continues to change with its environment. These changes must be considered in the initial design for a higher success rate during production.

Observations on the Data

When accounting for carbon storage, producing the chair worked out to emit, at 8.78kg of CO2e. However, the chair is only carbon neutral as long as it is in use. An estimated 11.6-15.9kg of CO2e will be released when it reaches its end-of-life.

The chair follows similar patterns to the previous pieces, with the production phase being the largest contribution to emissions. Wood was by far the most significant emission in production at 7.58kg CO2e, followed by the foam at 2.34 kg CO2e. The stage of production that occurs in the woodshop remains low at 0.688kg CO2e, with the largest contribution being eight hours of steaming, accounting for 0.37kg CO2e. Electric tools that run on a clean power grid emit a modest amount of carbon. Using techniques like steam bending to replace metal joinery proved to be a valid logic. For reference, the 11 bolts used in the chair emitted 0.674kg CO2e. However, the differences between streaming joints and using metal in joints were not huge; for comparison, two bolts emitted 0.3kg CO2e while two hours of steaming emitted approximately 0.1kg CO2e. The cleanest option would be simple wood joinery, but the aesthetic appeal and function of the bent pieces in this project are believed to help the furniture stay in use for a more extended period.

The foam emissions were based on polyurethane foam, and therefore, the partially soy-based foam used in this project is likely to have lower emissions. The greater volume of wood used in the chair increases the carbon stored in the piece. Transportation by a gas-powered vehicle was the greatest contribution to shipping and is attributed to picking up the wood. The chair emitted half as much carbon as the lamp per kilogram of material. So far, reading the label has been helpful to give quick insight into production stages and highlighting areas where a tremendous improvement can be made.

Emission Goals: Canada & Global

i

Canada pop	37590000	**World Pop**	7800000000
2030 Goal (Mt)	438	**2030 Goal (Gt)**	40
Kg	438000000000	**Kg**	40300000000000
Per Person	11652	**Per Person**	5167

ii **Product: Chair**

Total Cost	455.46	**A Co2e**	Cradle To Gate (Production)	9.45
Total Weight	17.59	**B Co2e**	Gate to Point of Sale (Transportation)	0.52
Built Weight	13.80	**C Co2e**	Point of Sale to Site (Transportation)	2.08
Total Co2e	0.00	**D Co2e**	Construction	0.66
Stored Carbon	-16.98	**E Co2e**	Operation	0.00
		F Co2e	End of Life	13.76
		G Co2e	Carbon Storage	-16.98

Table.18 *Summery of Data for Chair, Table by Author*

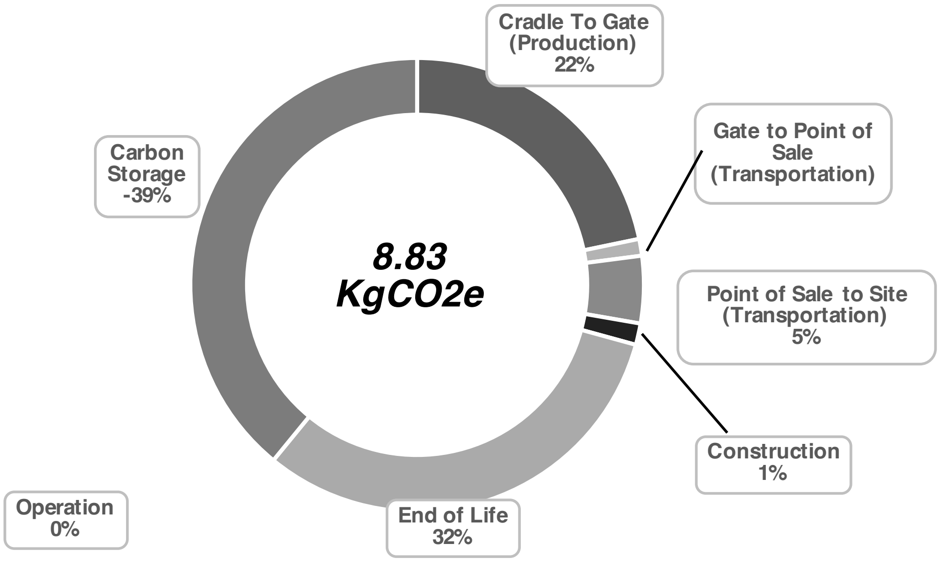


Table.19 *Chair Emission Phase Breakdown*

	Excellent		Very Good		Good		Fair		Poor	
	10	9	8	7	6	5	4	3	2	1
Adaptability	5+ Adaptable Uses	╲	4 Adaptable uses	╲	3 Adaptable Uses	╲	2 Adaptable Uses	╲	1 Adaptable Use	╲
Maintainability	90-100 % Replaceable Parts	80-90 % Replaceable Parts	70-80% Replaceable Parts	60-70 % Replaceable Parts	50-60 % Replaceable Parts	40-50 % Replaceable Parts	30-40 % Replaceable Parts	20-30 % Replaceable Parts	10-20 % Replaceable Parts	0-10 % Replaceable Parts
Reliability	>5x Standard Stresses	5.0x Standard Stresses	4.5x Standard Stresses	4.0x Standard Stresses	3.5x Standard Stresses	3.0x Standard Stresses	2.5x Standard Stresses	2.0x Standard Stresses	1.5x Standard Stresses	1.0x Standard Stresses
Recyclability	90-100 % Recyclable Parts	80-90 % Recyclable Parts	70-80% Recyclable Parts	60-70 % Recyclable Parts	50-60 % Recyclable Parts	40-50 % Recyclable Parts	30-40 % Recyclable Parts	20-30 % Recyclable Parts	10-20 % Recyclable Parts	0-10 % Recyclable Parts
Composability	90-100 % Compostable Parts	80-90 % Compostable parts	70-80% Compostable parts	60-70 % Compostable parts	50-60 % Compostable parts	40-50 % Compostable parts	30-40 % Compostable parts	20-30 % Compostable parts	10-20 % Compostable parts	0-10 % Compostable parts

Table.20 *Qualitative Assessment Chart for Chair, Table by Author*

(A) Cradle To Gate (Production)

Part	Quantity	Cost	Weight*	kg CO2e/kg	Source	CO2e
H.F. Ash	2	$41.48	14.160	0.3060	ICE	4.3330
Furn. Bolt	11	$1.49	0.220	3.0648	ICE/CEDA (GQ)	0.6743
Thrd. Insert	11	$3.66	0.081	3.0648	ICE/CEDA (GQ)	0.2495
						0.0000
Wool	1	$200.00	0.400	1.5946	CEDA (CB)	0.6378
						0.0000
Linen	1	$56.00	0.360	1.1978	CEDA (CC)	0.4312
Cotton Batt	1	$48.95	0.440	1.1978	CEDA (CC)	0.5270
Foam	1	$89.67	1.760	1.3316	CEDA (EV)	2.3436
Zipper (ft)	5	$3.82	0.048	0.9739	CEDA (CR)	0.0471
Snaps	4	$2.40	0.020	2.4695	CEDA (FT)	0.0494
Thread	1	$7.99	0.100	1.5946	CEDA (CB)	0.1595
						0.0000
Total		$455.46	17.590			9.45

*inc waste

Carbon Storage

Part	Quantity	Cost (Total)	Weight (Total)	kg CO2e/kg	Source	CO2e
Ash Total	1		10.680	-1.59	ICE	-16.9812
Total						-16.9812

Table.21 *Cradle to Gate Phase Emissions for Chair, Table by Author*

(B) Gate to Point of Sale (Transportation)

Part	Location A	Location B	MoT	Distance	CO2e/kg/km	Source	CO2e
H.F. Ash	Haliburton	Haliburton	NA	NA	NA	NA	
Furn. Bolt	Hamilton	Minden	Truck	540.000	0.000062	McKinnon	0.0074
Thrd. Insert	China	Vancouver	Ship	10011.700	0.000008	McKinnon	0.0065
Thrd. Insert 02	Vancouver	Mississauga	Truck	4418.880	0.000062	McKinnon	0.0223
Wool	Scotland	Montreal	Ship	5219.263	0.000008	McKinnon	0.0000
Wool 02	Montreal	Toronto	Truck	652.303	0.000008	McKinnon	0.0021
Linen	Lithuania	Montreal	Ship	7205.637	0.000008	McKinnon	0.0231
Linen 02	Montreal	Iroquois	Truck	467.838	0.000062	McKinnon	0.0104
Cotton Batt	Hendersonville	Grand Valley	Truck	1352.856	0.000062	McKinnon	0.0369
Foam	North America	Vaughn	Truck	2283.934	0.000062	McKinnon	0.2492
Zipper (ft)	Wenzhou	Vancouver	Ship	10011.700	0.000008	McKinnon	0.1410
Zipper 02	Vancouver	Mississauga	Truck	4377.880	0.000062	McKinnon	0.0131
Snaps	Clarkesville GA	Barrie	Truck	1514.770	0.000062	McKinnon	0.0019
Thread	Gutach	Montreal	Ship	6469.910	0.000008	McKinnon	0.0010
Thread 02	Montreal	Toronto	Truck	618.841	0.000062	McKinnon	0.0038
Total				55145.512			0.52

Table.22 *Gate to Point of Sale Phase Emissions for Chair, Table by Author*

(C) Point of Sale to Site (Transportation)

Part	Location B	Location C	MoT	Distance	CO2e/kg/km	Source	kgCO2e2
H.F. Ash	Haliburton	Minden	Car	53.970	0.192000	OWIN	2.0724
Furn. Bolt	Minden	Minden	Truck	53.970	0.000062	McKinnon	0.0007
Thrd. Insert	Mississauga	Minden	Truck	241.000	0.000062	McKinnon	0.0012
Thrd. Insert 02							0.0000
Wool	Toronto	Caledon	Truck	72.200	0.000062	McKinnon	0.0018
Wool 02							0.0000
Linen	Iroquois	Minden	Truck	129.000	0.000062	McKinnon	0.0029
Linen 02			Truck		0.000062	McKinnon	0.0000
Cotton Batt	Grand Valley	Caledon	Truck	45.500	0.000062	McKinnon	0.0012
Foam	Vaughn	Caledon	Truck		0.000062	McKinnon	0.0000
Zipper (ft)	Mississauga	Minden	Truck	241.000	0.000062	McKinnon	0.0007
Zipper 02							0.0000
Snaps	Barrie	Caledon	Truck	69.800	0.000062	McKinnon	0.0001
Thread	Toronto	Caledon	Truck	64.700	0.000062	McKinnon	0.0004
Thread 02							0.0000
Total				971.140			2.08

Table.23 *Cradle to Gate Phase Emissions for Chair, Table by Author*

(D) Construction

Task	Hours	kw of tool	kg CO2e/kwh	kgCO2e
Steaming	8	1.5	0.031	0.372
Cutting	2	1.8	0.031	0.1116
Planing	1	1.8	0.031	0.0558
Sanding	3	0.33	0.031	0.03069
Sewing	2	1.5	0.031	0.093
Total				0.66309

(E) Operation

Hours / Year	kw of tool	kg CO2e/kg	CO2e
NA	NA	NA	NA
Total			0

(F) End of Life

Landfill Transportation

Product	Weight	MoT	Distance*	CO2e/kg/km	Source	Co2e
Chair	13.80	Truck	50	0.000062	McKinnon	0.04278

Landfill Processing

Product	Weight	kg CO2e / kg	Source	CO2e
Chair	13.80	1.152	Jeffery Morris	15.8976

Recycling Transportation

Product	Weight	MoT	Distance*	CO2e/kg/km	Source	Co2e
Chair	13.80	Truck	250	0.000062	McKinnon	0.2139

Mixed Recycling Processing

Product	Weight	kg CO2e / kg	Source	CO2e
Chair	13.80	0.824	Jeffery Morris	11.3712

Table.24 *Construction, Operation, and End-of-Life Phase Emissions for Chair, Table by Author*

Built Photos

Figure.111 *Chair Back Perspective, Photo by Author*

Figure.112 *Chair Front Perspective, Photo by Author*

Figure.113 *Chair Frame Front Perspective, Photo by Author*

Figure.114 *Chair Frame Front Perspective, Photo by Author*

Figure.115 *Chair Frame```` Front Perspective, Photo by Author*

Figure.116 *Chair Seat Detail, Photo by Author*

Figure.117 *Chair Tripod Base, Photo by Author*

Figure.118 *Chair Base Detail, Photo by Author*

Figure.119 *Chair Cushion Fabric Detail, Photo by Author*

Figure.120 *Chair Back Fabric Detail, Photo by Author*

Bed

6.

Section Contents

Illustration.24 *Original Rendering of the Bed, Visualisation by Author*

"The industrial value of leisure as a promoter of the consumption of goods & thus as a stimulant to business, has been proved."

Henry Ford

Chapter 6 – Bed Case Study

Rest is essential for our health and productivity (Rosekind et al. 2010, 91-98). The initial industrial revolution brought a substantial increase in working hours for much of the working class (Hopkins, 1982). Labour movements and industrialists like Henry Ford championed the 40-hour workweek, suggesting that leisure would lead to increased spending, thus fueling the economy. It was thought that machines would drastically reduce humanity's workload, and in some respects, they did. However, it is increasingly common for people to feel that computers have ultimately elevated their workload (Gibbs, 1997). Presently, a culture of long working hours is expected to enable the production of more products and services for people to consume. Our "obsession with growth" and production is resulting in an ever-growing list of environmental challenges, while continuing to increase an already high GDP does not have proven benefits for society (Banerjee & Duflo, 2019). What if we produced and consumed less? Would we need to work as much? Would as many resources need to be extracted?

Artefact Description

A common reason to replace a bed frame is to be able to use a larger mattress. In the spirit of designing for an entire life, this bedframe is constructed to expand and accommodate mattress sizes ranging from twin to queen. It is a bed that can grow with a person. Bent wood members make up the back legs of the bed and extend to create a headboard. Two hollow wood channels at the head and foot of the bed allow a piece of wood to slide in and out from either side, changing the width of the bed frame.

Pine slats span from a lip on the inner face of the frame to a central member to create a platform; they alternate like a sliding finger joint to allow the frame to expand and contract. The rectangular bed frame features an angled headboard on which the user can comfortably lean against.

Illustration.25 *Bed Axonometric - Queen Size, Drawing by Author*

Orthographic Drawings

Illustration.26 *Bed Axonometric - Twin Size, Drawing by Author*

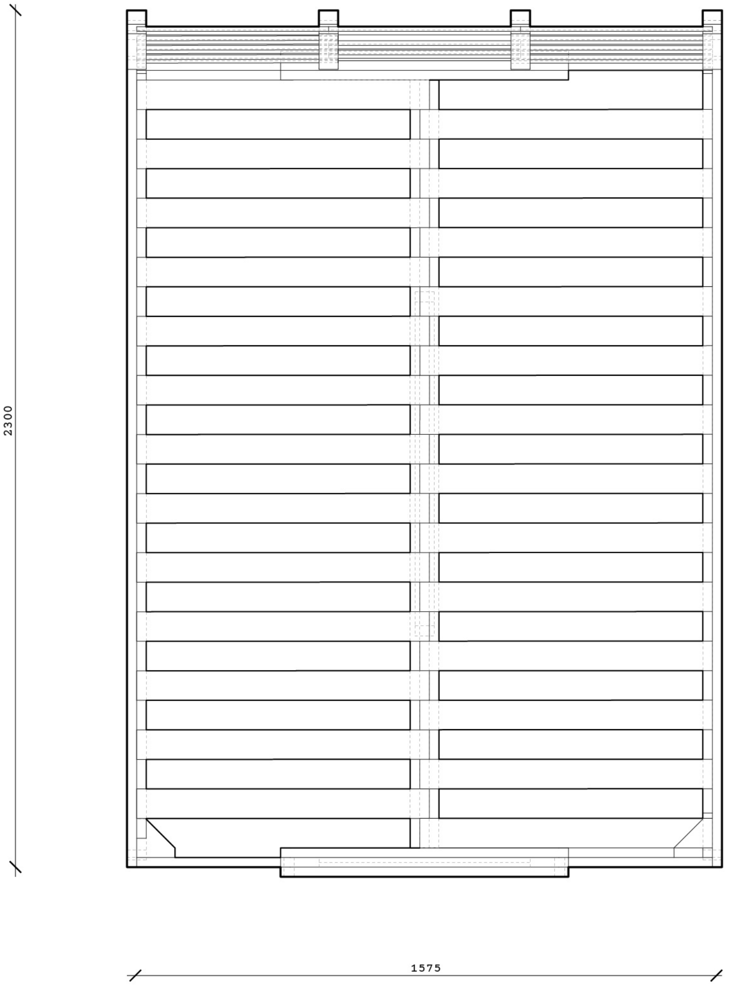


Illustration.27 *Bed Plan - Queen Size, Drawing by Author*

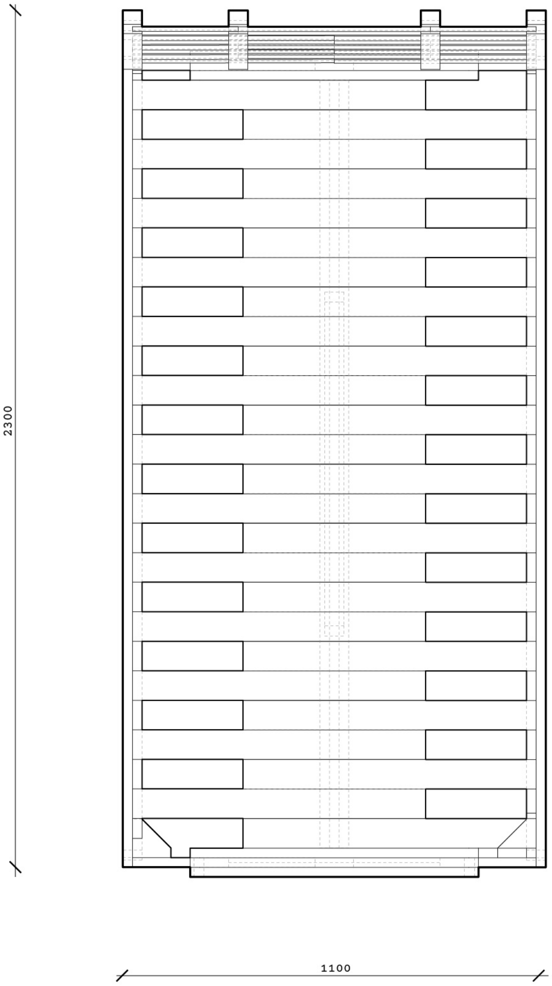


Illustration.28 *Bed Plan - Twin Size, Drawing by Author*

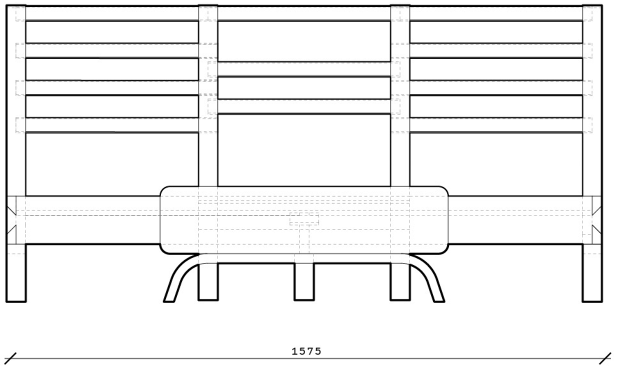


Illustration.29 *Bed Front elevation - Queen Size, Drawing by Author*

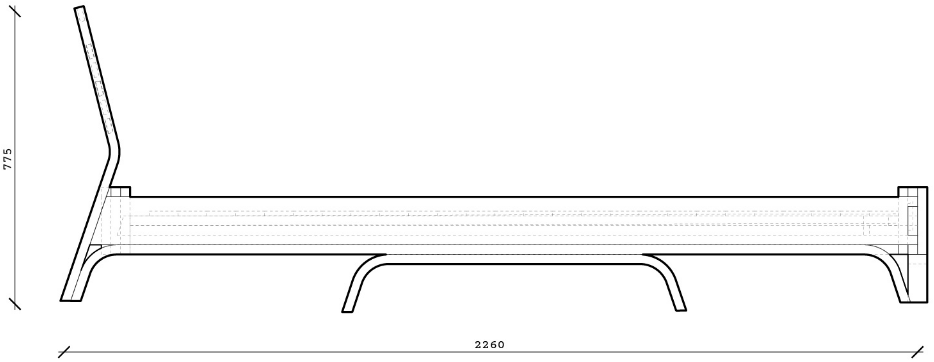


Illustration.30 *Bed Side Elevation, Drawing by Author*

Figure.121 *Bed Supply Chain Map - North American Scale, Map by Author*

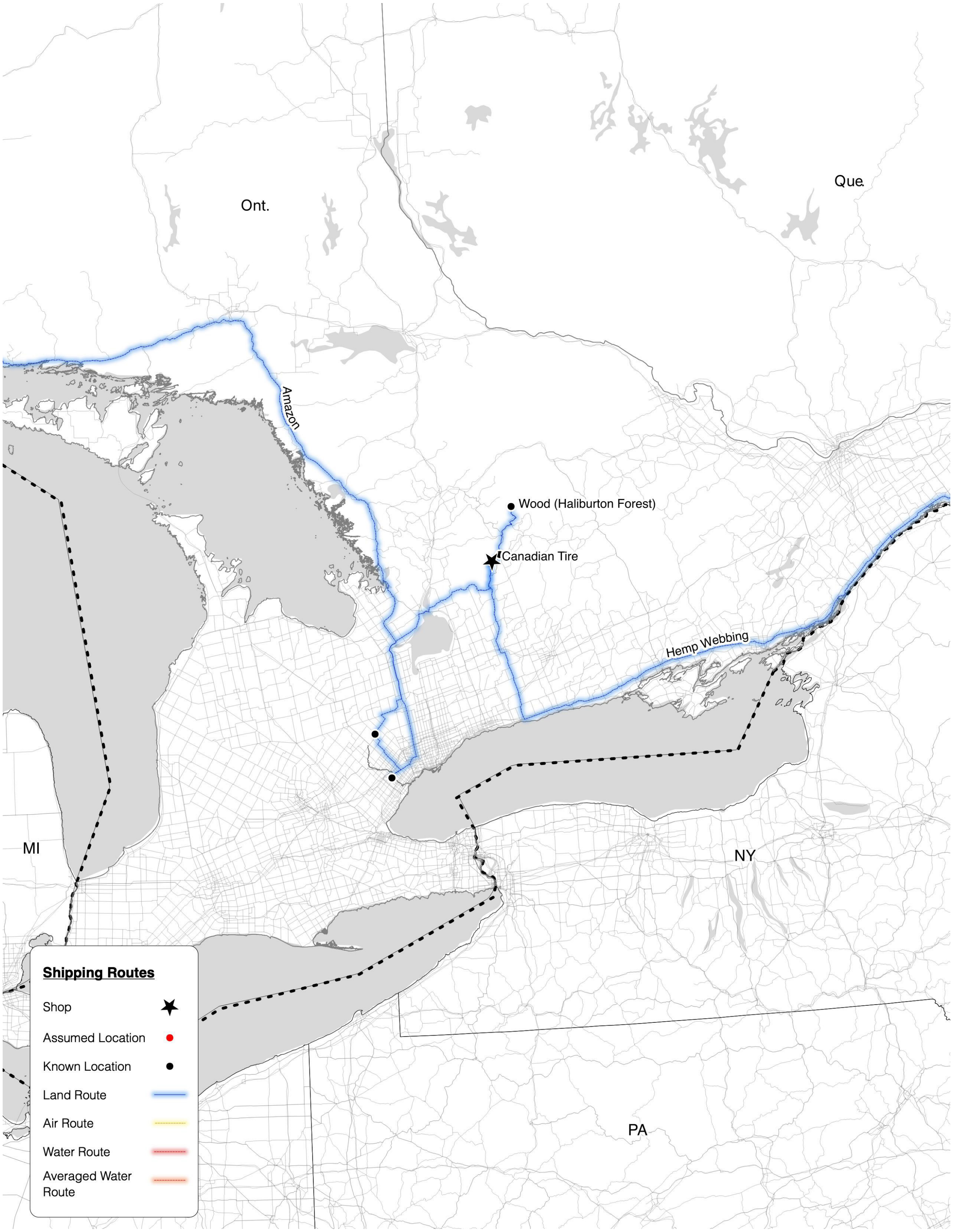


Figure.122 *Desk Supply Chain Map - Provincial Scale, Map by Author*

Figure.123 *Bed Sliding Cross Rail, Photo by Author*

Figure.124 Bed Side Rail, Photo by Author

Figure.125 *Bed Slats, Photo by Author*

Figure.126 *Bed Center Rail, Photo by Author*

Figure.127 *Bed Left Sliding Headboard Piece, Photo by Author*

Figure.128 *Bed Right Sliding Headboard Piece, Photo by Author*

Figure.129 *Bed Center Headboard Piece, Photo by Author*

Figure.130 *Foot Cross Rail Dovetail Joint, Photo by Author*

Figure.131 *Cross Rail Mortise & Tenon, Photo by Author*

Figure.132 *Chiseling Headboard Mortise, Photo by Author*

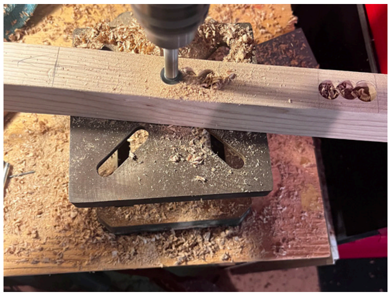


Figure.133 *Drilling Headboard Mortise, Photo by Author*

Figure.134 *Assembled Headboard in the Twin Size Arrangement, Photo by Author*

Construction Process

Despite being the largest of the prototypical furniture pieces, the bed's construction was simplified by its mostly rectilinear components. A mould with a 30-degree curve was built for the headboard / back legs. With the bend in the centre of the vertical member, the back legs and the headboard extend out at 15 degrees.

The Headboard

Four bent members act as the back legs of the bed and the headboard. The two central members are connected by three horizontal members that fix the width of the centre headboard. Two vertical members on the left and right outer edges of the headboard are intersected by three horizontal members that slide into the centre section of the headboard. When it contracts or expands from a twin to a queen mattress, these outer sections move with the bed frame—the three top horizontal rungs of the headboard slot into the vertical members. When changing the width of the bed, the topmost rung on the left and right headboard needs to be exchanged with an appropriately sized rung. These additional rungs act as a point of measurement indicating when the bed has been expanded to the desired size. Furniture bolts inserted near the midpoint of each vertical member connect the headboard to the bedframe, enabling easy transportation after disassembly in three separate pieces.

The Frame

The wooden cross rails at the head and foot of the frame slide into a central hollow core member. This hollow wooden channel was the first component of the frame to be built. Two 7in (17.8cm) wide boards were separated by a 1in (2.5cm) spacer at the top and bottom. The opening accepted the 1in (2.5cm) x 5 (12.7in) cross rail. The interior faces of the channel were sanded and coated in beeswax to help the boards slide. The corners of the footboard were connected to the side rail with a dovetail joint. A mortise and tenon joint connected

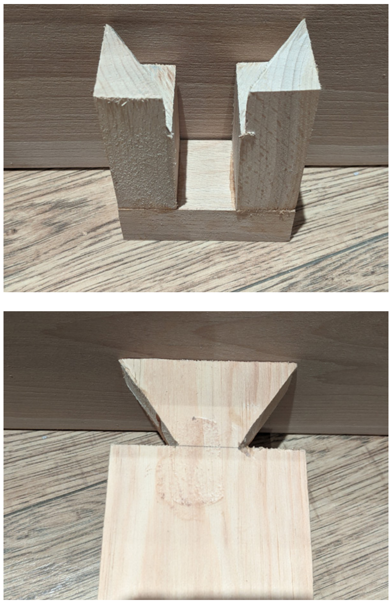


Figure.135 *Center Rail Connection Details, Photo by Author*

Figure.136 *Leg Dowel Connection, Photo by Author*

Figure.137 *Assembled Bed Slats in the Twin Size Arrangement, Photo by Author*

the side rail to the head crossbar. Braces at the corners make it possible to bolt the connection together; however, the friction of the joints is typically enough to keep the frame together. Two legs were screwed to the foot end of the side rails. Legs were also attached with dowels to support the channel pieces. A centre rail with a T-shaped cross-section connects to the head and foot cross rails with a version of a sliding dovetail joint. A short vertical member supports the central rail.

The Slats

A lip was fastened to the inner face of both side rails for the slats to rest. The slats were made of pine to keep the bed light. They span from the lip of the outer rails to the centre rail. Alternating and overlapping slats allow for movement when changing the bed's width. Staples attach a strip of hemp webbing to the outer edge of the slats; the inner face of the slats is left unrestrained for the sliding motion.

Figure.138 *Channel Assemble with Beeswax, Photo By Author*

Figure.139 *Assembled Cross Rail Detail, Photo By Author*

Carbon Label & Calculations

Carbon Facts

Item: Bed

Weight (kg)	55.82	kg
Emissions / kg	-0.03	CO$_2$e/kg
Total Emissions	92.37	kgCO$_2$e
Inc. Carbon Storage	-1.40	kgCO$_2$e
% Yearly Value*	0.31%	
Production	25.152	kgCO$_2$e
Transportation	11.547	kgCO$_2$e
End-of-life	55.669	kgCO$_2$e
Operation (Yearly)	0.000	kgCO$_2$e
Carbon Storage	-93.768	kgCO$_2$e

Lifespan Facts

Lifespan Goal	75	years
Cost / Year	3.3311	/yr.
Adaptability	Good	
Maintainability	Excellent	
Reliability	Very Good	
Recyclable Parts	Excellent	
Biodegradable Parts	Excellent	

Certifications

Sustainable Forestry	✓
Fair Trade	✓
Safe Workplace	✓

Ingredients

Beach Wood, Ash Wood, Pine Wood, Steel, Hemp

Table.25 *Bed Carbon Fact Sheet, Table By Author*

Discussion & Analysis

Observations on the process of making

As the last furniture piece built, the bed was made with the remaining boards of wood that were purchased months earlier. Some imperfections in the remaining wood were accepted instead of purchasing more lumber. The rough-cut beech boards show their characteristics better once planed, and some of the boards exhibited checking and slight discolouration. However, in the spirit of the project, the decision was made to work with the structurally sound, existing wood, even if it was not aesthetically perfect.

Like many of the wood components, the greatest challenge with the bed was wood shrinkage. When the bed frame was brought inside, the wood began to dry and shrink, resulting in two significant repercussions: the sliding cross rails became stuck in the channel, and some minor cracks became much more apparent. The crossbars of the frame and some steam-bent pieces affected by close-in were left under a tarp with a humidifier. Once the wood re-gained enough moisture and the pieces had expanded, the boards could be pulled out. While removing the boards, the dovetail joints were damaged, so a few pieces needed re-cutting. The cracks were filled with epoxy to prevent them from opening further.

The legs of the bed were intended to all be smaller steam-bent components. In the end, it was only the headboard that contained steam bent wood. By the time this final prototype was being built, there was a limited quantity of green ash left, and a vertical leg was more straightforward, strong, and less energy-intensive than a steamed piece. Learning to steam bend has been a rewarding experience and has highlighted that process should not only be a means to produce a preconceived idea. Process should complement and help inform a design. In the case of the bed, it was felt that steam-bent pieces were essential to the shape of the headboard but not necessary for all the legs. This decision saved time, money, and carbon while still achieving the desired outcome: a functional, adaptable, attractive, and comfortable bed.

The bed was a large piece for a single craftsperson to make. The time spent cutting and sanding components was greater than any of the previous pieces. Being the designer, supplier, maker, and user of these pieces provided a useful perspective on the process of making. Each phase of the process was longer than the one prior, meaning that the initial design phase was the shortest, followed by construction, leaving the end-use phase the longest. In an example pulled from the bed, the many sliding and fixed mortise and tenon joints took no time to design on the computer but resulted in hours and hours of careful chiselling during construction. It is a good lesson for any designer: the consequences of the decisions made in the design phase grow exponentially as a project is turned into a tangible thing.

Observations on the Data

The bed was the first piece to sequester enough carbon to offset the emissions released during its lifespan, resulting in a carbon-negative value on the label. The bed is the largest piece of furniture built for this project, and it is made almost entirely out of wood. The carbon-negative result is possible because, as previously mentioned, sustainably sourced wood can sequester carbon while in a preserved state. In this fourth round of observations, it was becoming clear which phases of the lifecycle would have the greatest emissions. Furniture that uses similar materials and construction processes has similar patterns in their emissions; like other pieces, the bed saw most of the emissions coming from its end-of-life wood decomposition, followed by the initial production of materials.

Approximately 25 kgCO2e came from production, the majority of which is attributed to the production of lumber. The bed is primarily a wood object, and to lower the carbon emissions in future iterations, it would be beneficial to investigate logging practices. The bed contains a total of -93.8 KgCO2e stored in the wood. Before its end-of-life carbon release, the bed reduced emissions by -59.2 kgCO2e. Transportation emissions for the bed were twice that of the desk or chair: a total of 8.5 KgCO2e. Shipping distances were not further for the bed components, but the larger material volume took responsibility for about half of the emissions released while picking up the wood.

Wood is favoured as a material in that the data represents its potential to sequester carbon; however, it is not a silver bullet for climate change. The carbon cycle is far more complicated than the label makes it seem. When we invest energy into creating an object, it is still helpful to have measurable data points to base future design decisions. Data can be misleading, and the way it is represented can significantly change the way people perceive information. The Carbon Label is an exercise in transparency. It attempts to communicate information that is not commonly seen or collected.

Emission Goals: Canada & Global

i

Canada pop	37590000	**World Pop**	7800000000
2030 Goal (Mt)	438	**2030 Goal (Gt)**	40
Kg	438000000000	**Kg**	40300000000000
Per Person	11652	**Per Person**	5167

ii **Product: Bed**

Total Cost	249.83	**A Co2e**	Cradle To Gate (Production)	25.15
Material Weight	80.88	**B Co2e**	Gate to Point of Sale (Transportation)	0.05
Built Weight	55.82	**C Co2e**	Point of Sale to Site (Transportation)	11.50
Total Co2e	36.70	**D Co2e**	Construction	3.35
Stored Carbon	-93.77	**E Co2e**	Operation	0.00
		F Co2e	End of Life	55.67
		G Co2e	Carbon Storage	-93.77

Table.26 *Summery of Data for Bed, Table by Author*

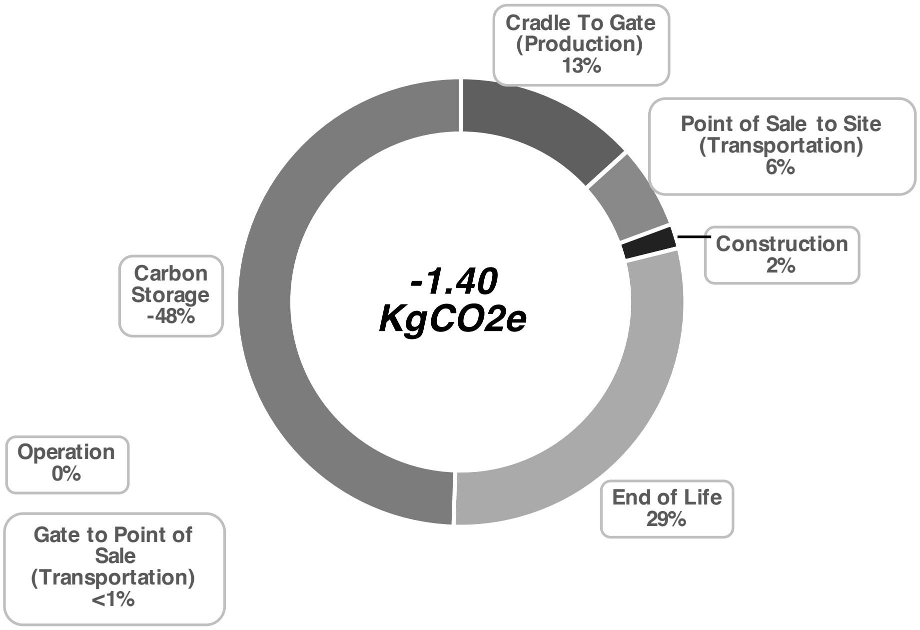


Table.27 *Bed Emission Phase Breakdown*

	Excellent		Very Good		Good		Fair		Poor	
	10	9	8	7	6	5	4	3	2	1
Adaptability	5+ Adaptable Uses	╲	4 Adaptable uses	╲	3 Adaptable Uses	╲	2 Adaptable Uses	╲	1 Adaptable Use	╲
Maintainability	90-100 % Replaceable Parts	80-90 % Replaceable Parts	70-80% Replaceable Parts	60-70 % Replaceable Parts	50-60 % Replaceable Parts	40-50 % Replaceable Parts	30-40 % Replaceable Parts	20-30 % Replaceable Parts	10-20 % Replaceable Parts	0-10 % Replaceable Parts
Reliability	>5x Standard Stresses	5.0x Standard Stresses	4.5x Standard Stresses	4.0x Standard Stresses	3.5x Standard Stresses	3.0x Standard Stresses	2.5x Standard Stresses	2.0x Standard Stresses	1.5x Standard Stresses	1.0x Standard Stresses
Recyclability	90-100 % Recyclable Parts	80-90 % Recyclable Parts	70-80% Recyclable Parts	60-70 % Recyclable Parts	50-60 % Recyclable Parts	40-50 % Recyclable Parts	30-40 % Recyclable Parts	20-30 % Recyclable Parts	10-20 % Recyclable Parts	0-10 % Recyclable Parts
Composability	90-100 % Compostable Parts	80-90 % Compostable parts	70-80% Compostable parts	60-70 % Compostable parts	50-60 % Compostable parts	40-50 % Compostable parts	30-40 % Compostable parts	20-30 % Compostable parts	10-20 % Compostable parts	0-10 % Compostable parts

Table.28 *Qualitative Assessment Chart for Bed, Table by Author*

(A) Cradle To Gate (Production)

*inc waste

Part	Quantity	Cost	Weight*	kg CO2e/kg	Source	CO2e
H.F. Ash	1	$17.28	14.160	0.3060	ICE	4.3330
H.F. Beech	7	$96.85	52.885	0.3060	ICE	16.1828
H.F. Pine	4	$26.68	13.360	0.2630	ICE	3.5137
Furn. Bolt	10	$1.49	0.200	3.0648	ICE/CEDA (GQ)	0.6130
Screws	12	$0.84	0.024	3.0648	ICE/CEDA (GQ)	0.0736
Thrd. Insert	10	$88.70	0.074	3.0648	ICE/CEDA (GQ)	0.2268
Strapping	1	$18.00	0.175	1.1978	CEDA (CC)	0.2093
Total		**$249.83**	**80.878**			**25.15**

Carbon Storage

Part	Quantity	Cost (Total)	Weight (Total)	kg CO2e/kg	Source	CO2e
Ash Total	1		9.290	-1.59	ICE	-14.7711
Beech Total			34.530	-1.59	ICE	-54.9027
Pine Total			15.500	-1.55445514	ICE	-24.0940547
Total						**-93.7678547**

Table.29 *Cradle to Gate Phase Emissions for Bed, Table by Author*

(B) Gate to Point of Sale (Transportation)

Part	Location A	Location B	MoT	Distance	CO2e/kg/km	Source	CO2e
H.F. Ash	Haliburton	Haliburton	NA	NA	NA	NA	0.0000
H.F. Beech	Haliburton	Haliburton	NA	NA	NA	NA	0.0000
H.F. Pine	Haliburton	Haliburton	NA	NA	NA	NA	0.0000
Furn. Bolt	Hamilton	Minden	Truck	540.000	0.000062	McKinnon	0.0067
Screws	Hamilton	Minden	Truck	541.000	0.000062	McKinnon	0.0008
Thrd. Insert	China	Vancouver	Ship	10011.700	0.000008	McKinnon	0.0059
Thrd. Insert 02	Vancouver	Mississauga	Truck	4418.880	0.000062	McKinnon	0.0203
Strapping	China	Montreal	Ship	7205.637	0.000008	McKinnon	0.0101
Strapping 02	Montreal	Iroquois	Truck	467.838	0.000062	McKinnon	0.0051
Total				23185.055			0.05

Table.30 *Gate to Point of Sale Phase Emissions for Bed, Table by Author*

(C) Point of Sale to Site (Transportation)

Part	Location B	Location C	MoT	Distance	CO2e/kg/km	Source	kgCO2e2
H.F. Ash	Haliburton	Minden	Car	53.970	0.192000	OWIN	1.0362
H.F. Beech	Haliburton	Minden	Car	54.970	0.192000	OWIN	7.3880
H.F. Pine	Haliburton	Minden	Car	55.970	0.192000	OWIN	3.0704
Furn. Bolt	Minden	Minden	Truck	53.970	0.000062	McKinnon	0.0007
Screws	Minden	Minden	Truck	54.970	0.000062	McKinnon	0.0001
Thrd. Insert	Mississauga	Minden	Truck	241.000	0.000062	McKinnon	0.0011
Strapping	Iroquois	Minden	Truck	129.000	0.000062	McKinnon	0.0014
Total				643.850			11.50

Table.31 *Point of Sale to Site Phase Emissions for Bed, Table by Author*

Bed

(D) Construction

Task	Hours	kw of tool	kg CO2e/kwh	kgCO2e
Steaming	4	1.5	0.031	0.186
Cutting	4	1.8	0.031	0.2232
Planning	4	1.8	0.031	0.2232
Sanding	8	0.33	1.031	2.72184
Total				3.35424

(E) Operation

Hours / Year	kw of tool	kg CO2e/kg	CO2e
NA	NA	NA	NA
Total			0

(F) End of Life

Landfill Transportation

Product	Weight	MoT	Distance*	CO2e/kg/km	Source	Co2e
Chair	55.82	Truck	50	0.000062	McKinnon	0.173042

Landfill Processing

Product	Weight	kg CO2e / kg	Source	CO2e
Chair	55.82	1.152	Jeffery Morris	64.3046

Recycling Transportation

Product	Weight	MoT	Distance*	CO2e/kg/km	Source	Co2e
Chair	55.82	Truck	250	0.000062	McKinnon	0.86521

Mixed Recycling Processing

Product	Weight	kg CO2e / kg	Source	CO2e
Chair	55.82	0.824	Jeffery Morris	45.9957

Table.32 *Construction, Operation, and End-of-Life Phase Emissions for Bed, Table by Author*

Built Photos

Figure.140 *Bed Frame Queen Size - Angle A, Photo By Author*

Figure.141 *Bed Frame Queen Size - Angle B, Photo By Author*

Figure.142 *Bed Frame Twin Size - Angle A, Photo By Author*

Figure.143 *Bed Frame Twin Size - Angle B, Photo By Author*

Figure.144 *Bed Frame Corner Detail, Photo By Author*

Figure.145 *Bed Frame Headboard Profile, Photo By Author*

Conclusion

7.

Section Contents

Chapter 7 – Discussion & Conclusion

Lessons From Building & Labelling

Extensive research should be done in the design phase. It is tough to make changes once building begins, and it can be tempting to cut corners. I fully understand and respect the challenges of transforming drawings into tangible things. Intense preparation before construction helps ensure the project matches the design intention and is built realistically.

Materials should be sourced before major design decisions are made. Otherwise, one must accept that a redesign may be needed after researching what supplies are available. In this project, looking for sustainable and local suppliers often took a similar amount of time to that needed for the design phase. Designers should strive to work closely with suppliers and break out of the habit of specifying materials simply because they have become an industry standard.

Carbon labelling involves cooperation from suppliers to share material ingredients and supply chains. During this project, it was common to not receive any response from large suppliers when asking about their supply chain. In some cases, companies responded by saying that their manufacturing location and material composition were proprietary information that they were unwilling to share. Smaller companies, who marketed themselves as offering sustainable products, were almost always pleased to provide the same information withheld by the larger companies. In the few instances that I could travel directly to the place where a material was made, people were very eager to discuss the project and exchange information. This type of relationship applied to materials like the wood from the Haliburton Forest and the wool fabric that was woven in Toronto. Designers should seek opportunities to interact with the people engaged in producing the materials used in their projects.

During the construction process, the workspace can become very hectic; planning set intervals to stop work and document the process or collect data is non-negotiable when analysing the final product objectively. Once something is built, time should be allotted to reflect on the process and ensure all necessary data has been collected. It can be tempting to stop once production is complete, but finding time to fill out the carbon labels and collect notes about challenges that occurred during construction is invaluable for future builds or publications. While mistakes are fresh in your mind, redesigning would be an effective strategy to improve a product. Architects do not have the opportunity to redesign a building for many years if the design is unsuccessful; this makes sharing data and process documentation even more important.

As the world weans itself off fossil fuels, it is beneficial to have products that can store carbon for the remainder of the century. Until our power grids and modes of transportation are decarbonised, it is challenging to produce an LCA label that is carbon negative. The real benefit of wood is found in the period when it can store carbon. That being said, it is crucial to understand the limitations of wood. When viewing the label, it appears more valuable in the long term to reduce emissions in the manufacturing process than to offset emissions with carbon storage. Counting wood as a negative carbon emission involves ensuring the lumber came from a sustainable source. If forests are being cut down faster than they are regrowing, then carbon stored in biomass is only transferring to a lumber product and is not, in fact, a negative.

Reflecting on the furniture, the lamp was executed very closely to the intended design, whereas the chair experienced the most post-design changes. Changes were made on the fly to continue the process of making. In retrospect, when changing a design or encountering a problem, it would be better to redesign the piece formally. While it is exciting to tinker and adjust mid-build, there are benefits to creating new drawings and considering the change across the entirety of the piece. At a commercial scale, this may mean starting another prototype, but for this project, it could have involved digitally remodelling. One example of a post-design decision was ordering the foam for the seat; the final product has a cushion that looks proportionately too large for the chair, and the density of the foam was slightly too firm. The proportions can still be tweaked in the future, and unexpected outcomes are part of a cycle of excitement and disappointment that comes with making things.

It is important to know when to continue developing a prototype and when to stop building because an experiment has served its explorational purpose. Finishing the chair left a feeling of satisfaction and an immediate desire to make another iteration. I now understand Wegner when he says, "If only you could design just one good chair in your life... But you simply cannot." Undoubtedly, if one loves to make, they will keep striving for the perfect chair.

Criticisms on Carbon Labelling

There are numerous rating systems to assess the environmental impact of buildings. The most popular systems are based on completion points in general categories. A more comprehensive analysis tool is life cycle assessment (LCA). Industry experts believe a better system is still needed. LCAs are challenging to complete, but tools like the *Carbon Facts Label* explored in this thesis propose bringing carbon emission data to a broader audience. There needs to be a national or global database for companies to access cradle-to-gate emissions data, transportation emissions data, and end-of-life data for specific materials and processes. The ICE and CEDA databases were two resources that made this carbon accounting design project possible. Discovering and piecing together data was one of the most significant challenges of the work; it is the main reason why more transparent and consolidated carbon data is needed. Using carbon data as a designer was difficult. The accessibility and usability of carbon data could be improved.

Literature often debates the importance of embodied vs operational energy (or carbon). Embodied carbon could be defined as the operational carbon from earlier project phases. A good portion of carbon emission reduction improves processes through better system and material choices. The proposed strategies for reducing emissions are constructing less, using what we have, building things to last, and lowering our operational and embodied energy requirements.

After the initial set-up of the carbon accounting system, populating the labelling becomes a much more reasonable task. Government databases would simplify the process so that smaller companies could produce a label. It opens opportunities to develop software that allows businesses to enter data to output their label or to create a company to certify products, similarly to the *Declare Label* from the green living institute.

It is okay to provide estimates as long as carbon emissions are not underestimated, and products use the same database. If a global database was proposed, there would be potential for companies to use their own data if they feel their manufacturing processes have lower emissions than the provided base value.

Debates around methodology and data accuracy are likely holding back the implementation of a universal system. Every system must start somewhere, and after creating my own, I respect what existing environmental rating systems have accomplished. The risk with any rating system is its reductive nature; large scale problems like climate change can never be fully simplified to a few metrics. Providing a label of multiple quantifiable metrics would offer more transparency than systems with a singular final score. Labels can be biased or misread; a category like carbon storage could lead to excessive investment in wood products that, in turn, would create new ecological challenges. The label categories were based on values of longevity and low-carbon emissions; a different group of people could prioritise different metrics that would entirely change how the label is read. The label is a living graphic that will transform as better data becomes available and more effective ways of communicating carbon emissions are developed. Hopefully, one day, carbon will no longer be the necessary assessment unit, and the label could evolve to be based on other units such as kilojoules or kilograms of waste.

Outlook

The label was always envisioned as a design tool for professionals and a communication graphic for consumers. The designer and the end-user should have access to the same product information. I don't believe we currently have the vocabulary to discuss carbon emissions. Ideally, if more items had carbon labels, we would be able to develop an intuition for what one kgCO2e looks like. Future projects could create documents that solely focus on explaining and contextualising carbon emission values in our day-to-day lives.

This thesis involved designing an assessment system and a set of furniture based on assumptions about which design decisions would result in a low carbon product. Now that a carbon label has been produced for each prototype, there is a documented reference point for future designs. The next step is to build another set of prototypes to improve the results of the first label. Setting a benchmark for carbon emissions was the primary focus for these initial prototypes. Going forward, it is critical to acknowledge the results of the label and actively work to improve the carbon-heavy phases of design.

Wood as a building material is a rich area for further study. The end-of-life emissions for wood were often the most extensive emission phase. In some way, the end-of-life emissions are counteracted by wood's ability to store carbon. There is a great potential to have a carbon-negative LCA if we design better disposal/recycling processes for wood buildings and products.

A future study related to this work could involve sampling a group of people to understand if a carbon emissions label changes consumer behaviour. Carbon labelling opens opportunities to create legalisation for carbon caps on products or a requirement to disclose materials and emissions.

Steam bending became a primary fabrication method in all the furniture prototypes. A large amount of information on how to steam bend was acquired from online forums, videos, and experimentation. There is ample room for a research project focused solely on documenting and perfecting the process of steam bending. The literature on steam bending varied greatly from highly scientific analyses of wood cells to general furniture making guides. With more time, it would be interesting to test the applications of steam bending in a larger scale architectural context.

At the onset of this research, the intention was to test a method for integrating a carbon emission assessment into the design process. While building furniture was chosen to give the project a reasonable scope, the intention was to develop a methodology that could be applied at the scale of architecture. Applying a similar approach to a small residential building is a future aspiration for this work.

Carbon Labels inform the architectural design process by requiring deep thought about materials, processes, and building lifecycle. Completing a carbon assessment provides clear direction for reducing emissions when iterating designs. Designers can make informed decisions about products they are specifying in their projects when individual materials and products state their emissions on a label.

This thesis set out to develop its own environmental rating system while creating and assessing four prototypical pieces of furniture. The work was driven by the desire to develop a better understanding of carbon emissions, identify the carbon-heavy phases of design, and create a Carbon Label for each piece of furniture. The fabrication method of stream bending along with each material selection were all choices made with the label in mind. Prototypes for a lamp, desk, chair, and bed were successfully made. The carbon emissions of every component were documented to the best of my ability.

The combined total emissions for all the furniture pieces over their lifespans is 135.01 kgCO2e. When including carbon storage, that number drops to 21.17 kgCO2e. The item with the highest emissions per kilogram of material (inc. carbon storage) was the lamp (3.17 kgCO2e/kg), followed by the chair (1.87 kgCO2e/kg), the desk (0.42 kgCO2e/kg), and least of all, the bed (-0.03 kgCO2e/kg). In the case of wood furniture, the greatest areas in which to reduce emissions were the extraction/production of raw material and the end-of-life/disposal phases. These two phases exist at opposite ends of the product's lifespan and illustrate the importance of designing with all phases in mind.

On a planet with finite resources, it is essential that we continue to evaluate our relationship to making. Discussing, documenting, and labelling introduce transparency into the design process and enable future generations to build a better world.

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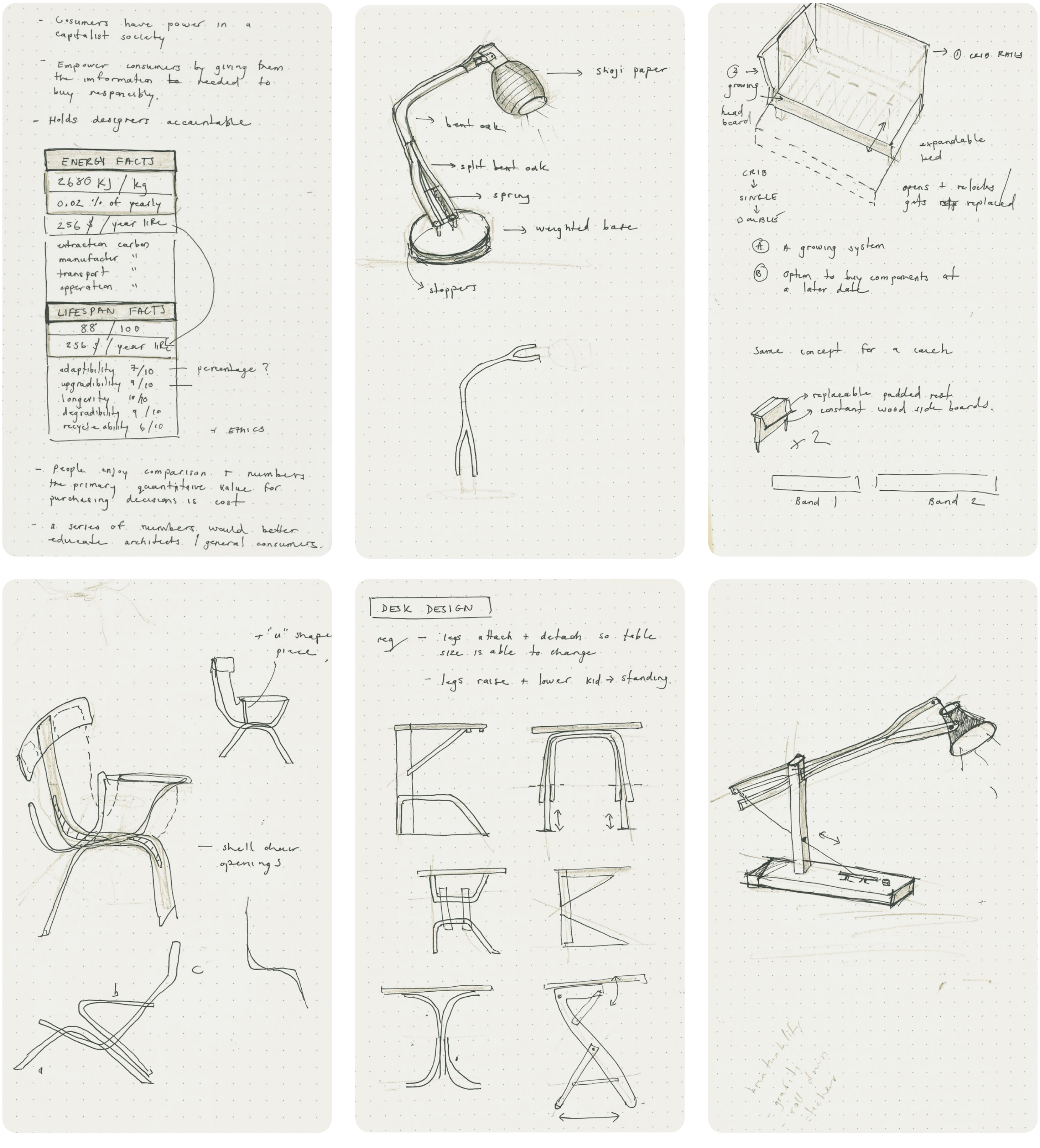
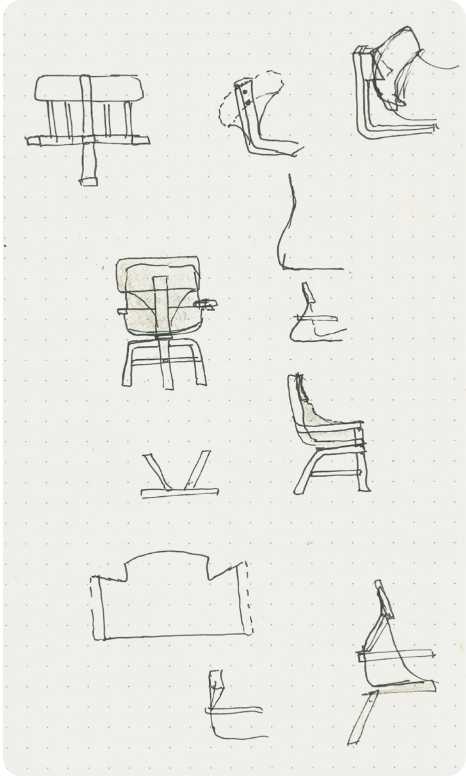
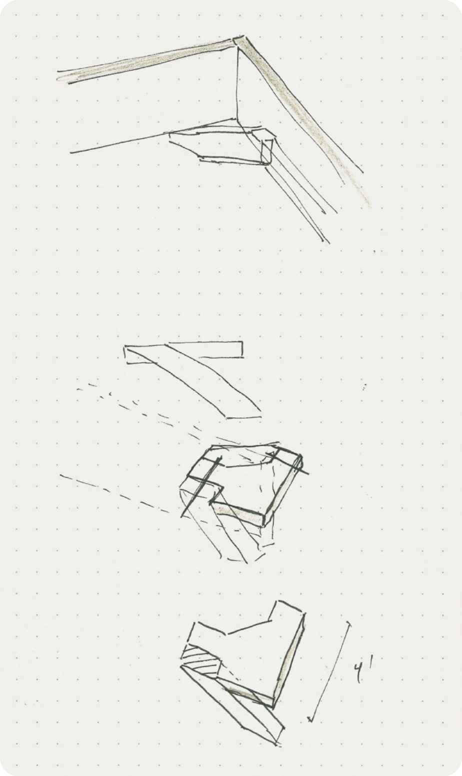


Figure.146 *Collection of Process Sketches*

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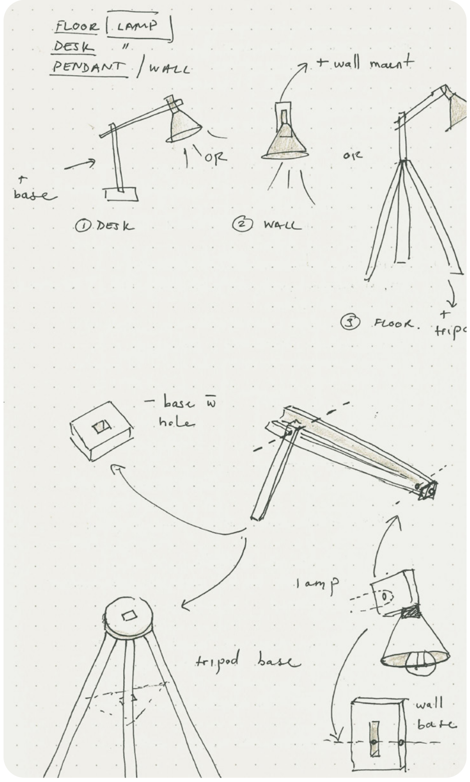
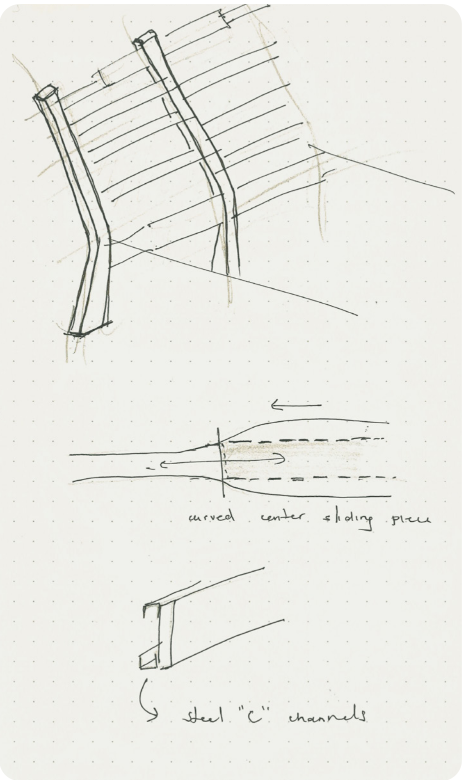

FLOOR LAMP
DESK "
PENDANT / WALL
+ wall mount
+ base
1 OR
OR
① DESK
② WALL
③ FLOOR.
+ tripo
- base w̄ hole
lamp
tripod base
wall base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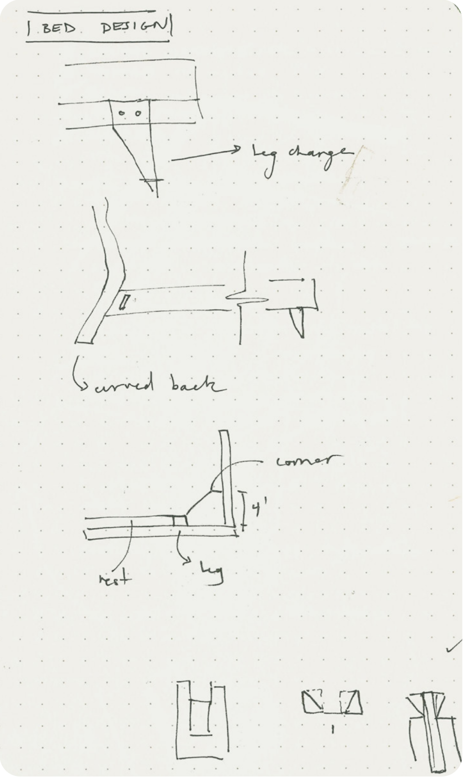
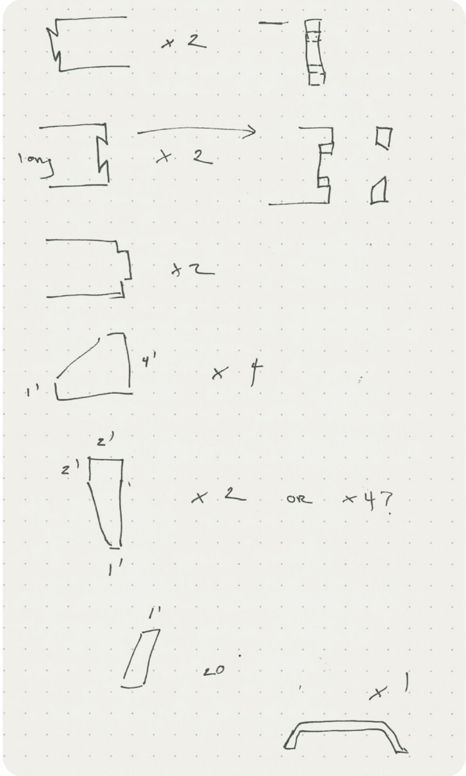
steel "C" channels


BED DESIGN
leg change
curved back
corner
4'
rest
leg
1


x 2
long
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x 2
4'
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2'
x 2 OR x 4?
1'
1'
20
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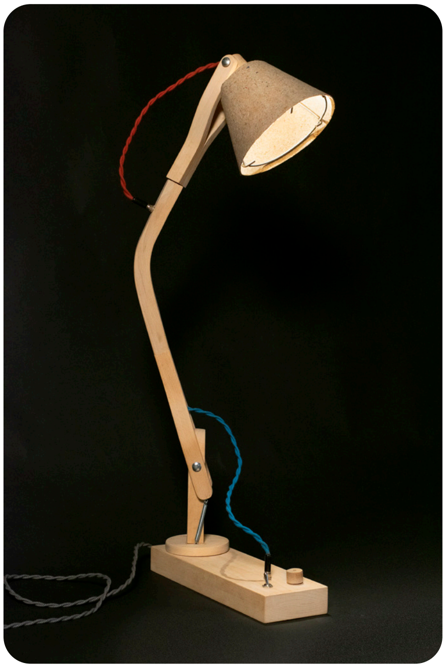

Carbon Facts

Item: Lamp

Weight (kg)	2.32	kg
Emissions / kg	3.17	CO$_2$e/kg
Total Emissions	7.38	kgCO$_2$e
Inc. Carbon Storage	4.18	kgCO$_2$e
% Yearly Value*	0.06%	
Production	3.785	kgCO$_2$e
Transportation	1.246	kgCO$_2$e
End-of-life	2.314	kgCO$_2$e
Operation (75yrs)	0.0116	kgCO$_2$e
Carbon Storage	-3.180	kgCO$_2$e

Lifespan Facts

Lifespan Goal	75	years
Cost / Year	2.4038	$/yr
Adaptability	Good	
Maintainability	Excellent	
Reliability	Fair	
Recyclable Parts	Very Good	
Biodegradable Parts	Very Good	

Certifications

Sustainable Forestry	✓
Fair Trade	✓
Safe Workplace	✓

Ingredients

Beech Wood, PVA Glue, Steel, Recycled Newsprint, Copper, PVC, Rubber, Cotton, Glass

Carbon Facts

Item: Desk

Weight (kg)	22.92	kg
Emissions / kg	0.42	CO$_2$e/kg
Total Emissions	46.06	kgCO$_2$e
Inc. Carbon Storage	9.61	kgCO$_2$e
% Yearly Value*	0.20%	
Production	15.920	kgCO$_2$e
Transportation	7.277	kgCO$_2$e
End-of-life	22.858	kgCO$_2$e
Operation (Yearly)	0.000	kgCO$_2$e
Carbon Storage	-36.443	kgCO$_2$e

Lifespan Facts

Lifespan Goal	75	years
Cost / Year	2.678	$/yr
Adaptability	Good	
Maintainability	Excellent	
Reliability	Fair	
Rcycable Parts	Excellent	
Biodegradable Parts	Excellent	

Certifications

Sustainable Forestry	✓
Fair Trade	✓
Safe Workplace	✓

Ingredients

Ash Wood, Steel, PVA Glue

Figure.147 *Set of Completed Labels & Furniture*

Carbon Facts

Item: Chair

Weight (kg)	13.8	kg
Emissions / kg	1.87	CO$_2$e/kg
Total Emissions	25.82	kgCO$_2$e
Inc. Carbon Storage	8.83	kgCO$_2$e
% Yearly Value*	0.00%	
Production	9.452	kgCO$_2$e
Transportation	2.600	kgCO$_2$e
End-of-life	13.763	kgCO$_2$e
Operation (Yearly)	0.000	kgCO$_2$e
Carbon Storage	-16.981	kgCO$_2$e

Lifespan Facts

Lifespan Goal	75	years
Cost / Year	6.0727	$/yr
Adaptability	Fair	
Maintainability	Excellent	
Reliability	Good	
Recyclable Parts	Excellent	
Biodegradable Parts	Excellent	

Certifications

Sustainable Forestry	✓
Fair Trade	✓
Safe Workplace	✓

Ingredients

Ash Wood, Steel, Nylon Zipper, Wool, Cotton, Polyester

Carbon Facts

Item: Bed

Weight (kg)	55.82	kg
Emissions / kg	-0.03	CO$_2$e/kg
Total Emissions	92.37	kgCO$_2$e
Inc. Carbon Storage	-1.40	kgCO$_2$e
% Yearly Value*	0.31%	
Production	25.152	kgCO$_2$e
Transportation	11.547	kgCO$_2$e
End-of-life	55.669	kgCO$_2$e
Operation (Yearly)	0.000	kgCO$_2$e
Carbon Storage	-93.768	kgCO$_2$e

Lifespan Facts

Lifespan Goal	75	years
Cost / Year	3.3311	/yr.
Adaptability	Good	
Maintainability	Excellent	
Reliability	Very Good	
Recyclable Parts	Excellent	
Biodegradable Parts	Excellent	

Certifications

Sustainable Forestry	✓
Fair Trade	✓
Safe Workplace	✓

Ingredients

Beach Wood, Ash Wood, Pine Wood, Steel, Hemp