form follows availability

the reuse revolution

Master's Thesis

Taleen Astrid Josefsson

Transformation Conservation
Co-Supervisors: John Helmfridsson & Anita Ollár
Examiner: Liane Thuvander
Spring 2019

Department of Architecture and Civil Engineering
Chalmers University of Technology

Form Follows Availability: The Reuse Revolution
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Program: Architecture & Planning Beyond Sustainability (MPDSD)

ABOUT THE AUTHOR

Taleen is a Swedish-American designer who grew up and received her Bachelor of Architecture in the USA. After working as an architectural and interior designer in the New York metropolitan area, she realized the need for architects with a deep knowledge of sustainable design of the built environment with a holistic approach to help tackle the complex climate, environmental, and social issues facing the world's current and future populations. While this thesis investigation focuses on the reuse of building materials from the existing building stock as a way to reduce the building industry's large negative impact on the environment, her interest in sustainability reaches beyond the technical and material aspects of construction; it includes a wide range of topics under the umbrella of sustainability, including human health, social constructs and values, consumerism, etc., all of which affect the environment humans share with nature.

ACKNOWLEDGMENTS

Thank you to all who have taken the time to share their experiences and provide insight into the current status of sustainability, circularity, material flows, reuse, and the construction industry as it stands today.

Special thanks to my supervisors and examiner, John, Anita, & Liane, for their expertise, critique, and support throughout the project.

Additional thanks to Eric, Julia, Jimmy, and all of my classmates for the help and encouragement throughout the past two years.

Finally, thank you to Danielle for her editing assistance and many years of inspiring conversation.

Figure 3: Mariestad's recycling center (November 2018)

ABSTRACT

In a time of calls to action to address climate change and environmental degradation, the construction industry is under fire for the large part it plays in the global environmental crisis. Architects are highly influential in determining the materials, methods, and overall footprint of construction and therefore play a key role in changing the course of the industry. Architects can disrupt the current cycle of wasteful material usage by choosing to specify reused materials found in the existing building stock. Such a choice is not simple: it requires intervention in the existing social, economic, and regulatory systems to be successful. The purpose of this thesis is to provide an understanding of the global issues related to climate change and the overuse of resources, as well as to apply site-specific solutions to a smaller, local context as an example of environmental impact reduction. Such an approach generates realistic design strategies which demonstrate that material reuse is not only possible but also desirable. The methods of exploration included: systems design; literary, material, and detail studies; visits to reuse projects; participation in a conference; and discussions with a wide range of experts on the subject. Research on the possibilities for material reuse in the construction industry were conducted in tandem with a building design proposal employing the concept of circular design. The proposal not only takes into account the lifetime of the materials specified but also the lifetime of the building itself; it must remain flexible to maintain resilience against changing functions, cultural perceptions, and climatic conditions. Limited to the confines of the existing system, it is difficult to design a building solely with reused materials; however, by constructing with materials already in circulation, the speed of material flow is slowed, waste is prevented, and the building's embodied energy is reduced. The research findings and design proposal act as a convincing argument for architects, clients, and contractors alike to employ material reuse as an effective means to reduce the building industry's negative impact on the environment.

Key words:
Reuse ▪ circular economy ▪ design for reuse ▪ adaptability ▪ material life cycle

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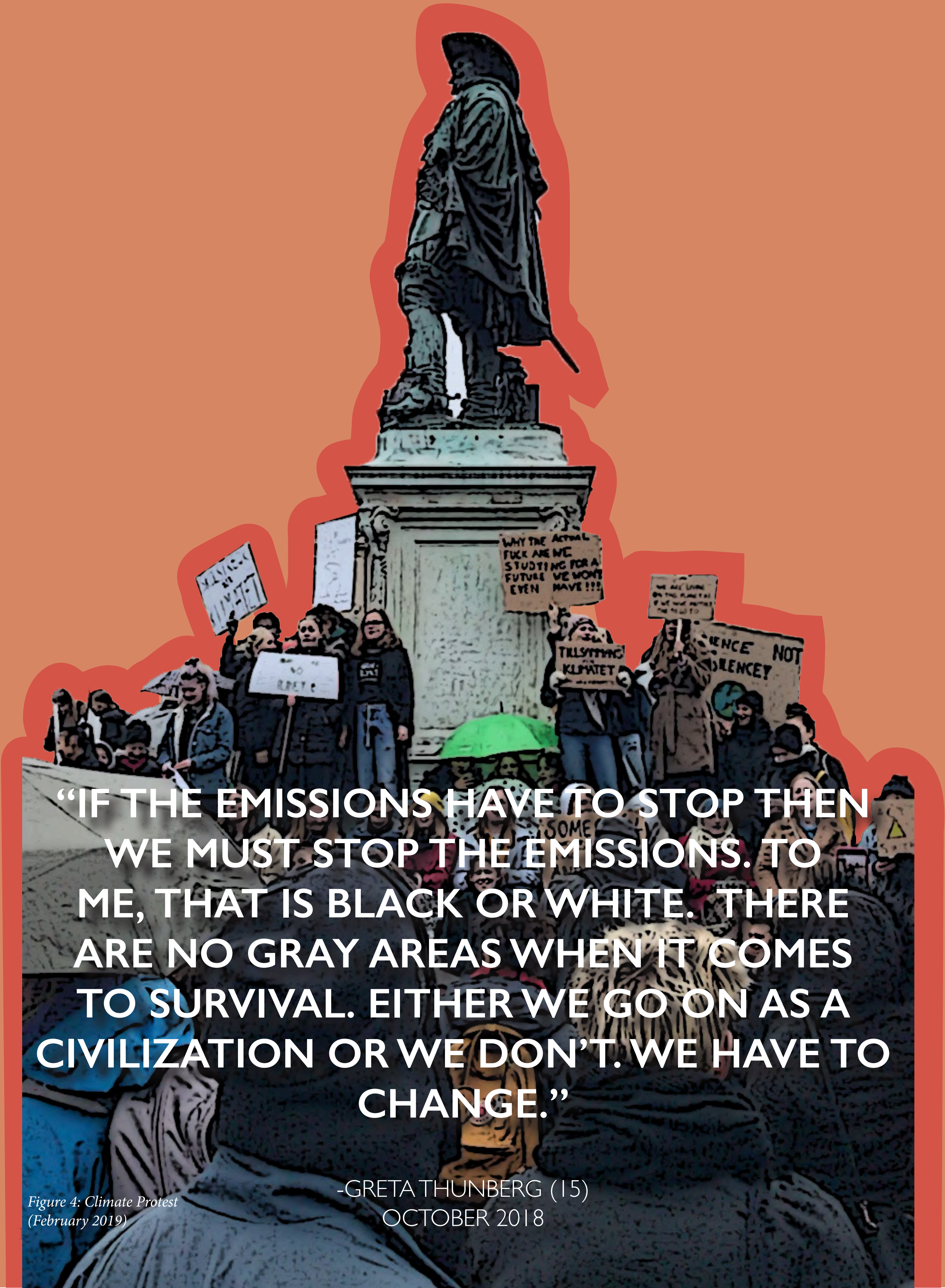
PART ONE



"IF THE EMISSIONS HAVE TO STOP THEN WE MUST STOP THE EMISSIONS. TO ME, THAT IS BLACK OR WHITE. THERE ARE NO GRAY AREAS WHEN IT COMES TO SURVIVAL. EITHER WE GO ON AS A CIVILIZATION OR WE DON'T. WE HAVE TO CHANGE."

-GRETA THUNBERG (15)
OCTOBER 2018

Figure 4: Climate Protest (February 2019)

INTRODUCTION

PERSONAL STATEMENT

I am becoming increasingly concerned with the state of the world, specifically with the threat that climate change poses to our planet and its inhabitants. We need to make immediate radical changes to ensure our future survival.

While I was initially drawn to the artistic elements of architecture, such as its potential for creating beauty and its ability to express a place's and a people's identity and culture, I have found that it is far more than that. An architect's decisions can permanently affect individuals, communities, and environments. Architects therefore have a responsibility to ensure that their designs enhance the wellbeing of humans, as well the surroundings.

A vicious cycle of fast construction for short term needs, values, and economic gains; poor construction quality; and ultimate demolition to make way for "new" construction is perpetuated by the growing consumption of aesthetic trends and the idea that economic growth is the main indicator of a successful society. There seems to be a lack of awareness of (or intentional disregard for) the increasing rate of raw material consumption, its finite amount, and the energy and material wasted as a result. This mindset is not sustainable; we have come to the point where the effects of this cycle not only impact the health of the environment but also continue at the cost of other humans near and far.

Architects are uniquely positioned in the construction industry system. They are the spiders in the web of the client (the project driver), builder, material suppliers, governing agencies, academia, the sciences, the arts, culture, history, people, and the environment, both natural and built. In designing for the client, the architect must mediate between all of the variables involved. This position is inherently powerful; his or her ultimate design decisions affect each variable, in a system where all variables are connected. In acknowledging this power, the architect may induce change where change is required to move towards a construction industry that does not merely reduce its negative impact on people and the environment, but affects them positively.

This thesis investigation defines the current system in which the construction industry operates, the role the architect plays in decision making, the resulting consequences, the leverage points at which positive interventions can be made to improve the situation, and finally provides an example of how architects can design and build better in a case study grounded in a local Swedish context.

Despite daily bombardment of threatening news stories and warnings about the very real dangers of climate change, we have a short window of time in which take action. If we do so now, we can safeguard the environment for ourselves and future generations.

NOTE TO THE READER

This thesis is the continuation of a project previously carried out by the author as part of a team of three students in Fall 2018 as part of the course *Planning and Design for Sustainable Development in a Local Context* at Chalmers University, led by Lena Falkheden. While a great deal of research, analysis, and text from the previous project is referenced here, the case study presented in this thesis is unique. The corresponding report is *Reuse Within Reach: Exploring, Collecting and Testing the Method of Reuse in Building Processes* by S. Jonasson, T. Josefsson, and S. Marklund (2019).

BACKGROUND

While many parties are motivated to take action against human impact on the climate, the term "sustainability" has become generic, overused, and often employed in the greenwashing of companies and their campaigns. Not only has it been overused, but the widely accepted understanding of sustainability, which implies doing no harm, is insufficient. So much damage has been inflicted on the planet that it is now necessary to do good in order to counteract the destruction and work towards environmental healing.

While some individuals, companies, and governments express interest in reducing their environmental impacts, their slogans ring hollow when their actions do not address the core issues of climate change.

The following investigation looks at the ongoing work of practicing professionals, academics, and researchers who are truly working towards solutions. These include the architecture firms Vandkunsten and Lendager Group who are working with material reuse and circular design in Denmark, stakeholders in the EU-funded BAMB (Buildings as Material Banks) project, and ground-up activists, to name a few.

Material reuse as a strategy for reducing the construction industry's environmental impact is not a new concept. There are many historical examples, such as *spolia* from the Roman Empire. In more recent Swedish history, literature on the topic of building and component reuse of contemporary materials can be found from the 1990s, but the ideas have not been widely adopted in practice. The topic of reuse is now experiencing a resurgence as the industry realizes it will not be able to keep up with the material and construction demands of the growing population.

PROBLEM STATEMENT

The construction industry holds immense power in not only shaping the built environment in which people spend the majority of their lives but also changing the way people use materials and energy which, as of 2017, is responsible for the largest share of global energy use and emissions across all sectors (United Nations Environment, 2018). In fact, according to the UN's 2018 Emissions Gap Report, global emissions and resource use have increased over the past year despite dire warnings of their impact on climate change. Architects have the ability and responsibility to demand movement towards a sustainable building industry; an important step towards sustainability is intervening in the existing linear material flow and implementing circular material thinking in design and construction.

While materiality is a central element of the reuse concept when approaching the issue through the lens of architecture, one must also consider how economy, building regulations, and social habits and perceptions all contribute to perpetuating a way of life that is known to be unsustainable.

RESEARCH QUESTIONS

1. How can an architect rethink the existing wasteful linear materials system by designing for the long term, employing circular design as a guiding concept?

2. How can materials salvaged from their first use be evaluated, collected, and made available to designers, contractors, and private individuals to encourage material reuse as a common practice in construction and renovation?

3. How can building materials and components be connected and assembled in such a way that they can continue their lives after each respective use without losing value?

AIMS

1. Identify how the existing building materials system (including supply, transport, architectural specification, desirability) operates according to social norms, economy, environment, and building industry workflows

2. Identify the current material flow system flaws in the local Mariestad area, specifically in relation to the building industry

3. Identify areas of improvement necessary in order to move towards a more circular materials economy

OBJECTIVES

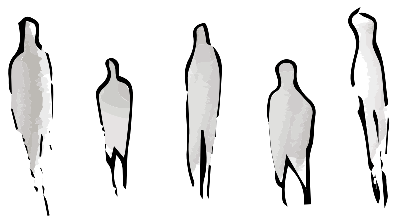
1. Provide healthy built environments for all:
   - the users
   - the public
   - builders
   - material and product producers
   - the environment

2. Reduce the construction industry's negative environmental impact

3. Reduce waste

AUDIENCE

Practicing architects, contractors and building industry tradesmen, developers, potential clients, and authorities with influence over building industry rules and regulations



METHODS OF INVESTIGATION

The thesis investigation was conducted using a combination of methods. The method types listed below describe the concepts and their value in the investigation process. The various methods were carried out simultaneously throughout the semester.

1. RESEARCH FOR DESIGN

An investigation of the current status quo and ongoing or completed work relating to material reuse was required to inform not only how the design process should be conducted but also affected the ultimate design expression.

2. INTERVIEWS, SITE VISITS & DISCUSSIONS

Connecting with professionals and people working across all sectors involved with or affecting the building industry provided insight into the current state of affairs in regard to the material reuse and upcycling concept: ambitions, feasibility, hurdles and difficulties, supply and demand, material flows, etc. Each interaction informed the thesis investigation, both widening and narrowing the questions and affecting the final result. Figure 5 to the right illustrates the network of interviewees consulted throughout the investigation.

3. TIME PERSPECTIVE

Considering the lifetime of a material, component, building, and site implies designing with and for the passage of time as a central aspect.

4. LITERATURE STUDIES

A variety of books, reports, articles, and websites published by practicing architects, academics, researchers, and research institutions were consulted to gain a broad understanding of ongoing or completed work in material reuse and circular economy, as well as specific information, such as construction details and data to support this thesis' arguments. Criteria for choosing the literature included:

- Text in English, Swedish, Norwegian, or Danish
- Texts by credible authors, such as literature published by well-regarded academic, scientific, or research institutions and peer-reviewed publications
- Texts relating directly to the topics of materiality, building, construction detailing, circular economy, design for reuse, and climate change

5. MATERIAL STUDIES

Identifying locally available materials and finding solutions for material reuse or how the available materials may be used in new ways as construction elements. This is done through creating material inventories of existing buildings, finding usable materials in secondhand building markets, and evaluating the materials. This included a structural prototype experimentation phase.

TOOLS OF COMMUNICATION

CALCULATIONS: LIFE CYCLE ANALYSIS

To the extent that the calculations provided in this thesis are within the constraints of time and ability, these provide hard, indisputable proof of the pros and cons of material and construction choices, broadening the conversation to make it accessible to those interested in quantitative facts.

CASE STUDY

The case study puts the researched theory and techniques into practice, transforming concepts into a design proposal.

COLLAGE

This is used as a visual representation tool to convey the underlying concept of construction (in this case with reused materials), which is essentially assembling elements in both traditional and unexpected ways, or in ways that may not have been originally intended.

DESIGN SYSTEMS

Mapping & diagramming to make legible the connections and relationships of a complicated system (the building industry and all of its related influences)

JOURNAL

Journal entries and periodic eflection aided in summarizing thoughts and lessons learned from interviews, conference lectures, and site visits. Informal summaries can be found in Appendix I.

PERSPECTIVES
INTERVIEWS & DISCUSSIONS

The majority of the research performed has been conducted by corresponding with people actively working in construction, design, and waste loop circulation today in the European context. Research included attending the BAMB conference (Buildings as Material Banks) in February 2019. A visualization of the network of contacts built from these interviews is shown in Figure 5 below.

As architectural and building industry work related to circular economy and material and component reuse of modern materials is still quite experimental in modern societies, there are not many tried-and-true nor fully successful built projects and methods available to study from afar.

With the onslaught of large-scale, machine-constructed buildings filled with highly processed, man-made materials of questionable dangerous chemical content, implementing material reuse is not so simple. Meeting with professionals working with these topics in the construction industry has resulted in in-depth conversations about the possibilities and barriers perceived and experienced when attempting to work or considering working with circular thinking. These conversations have provided a holistic understanding of the current situation and informed the design process.

Full interview and BAMB conference lecture summaries can be found in Appendix I.

INTERVIEW NETWORK

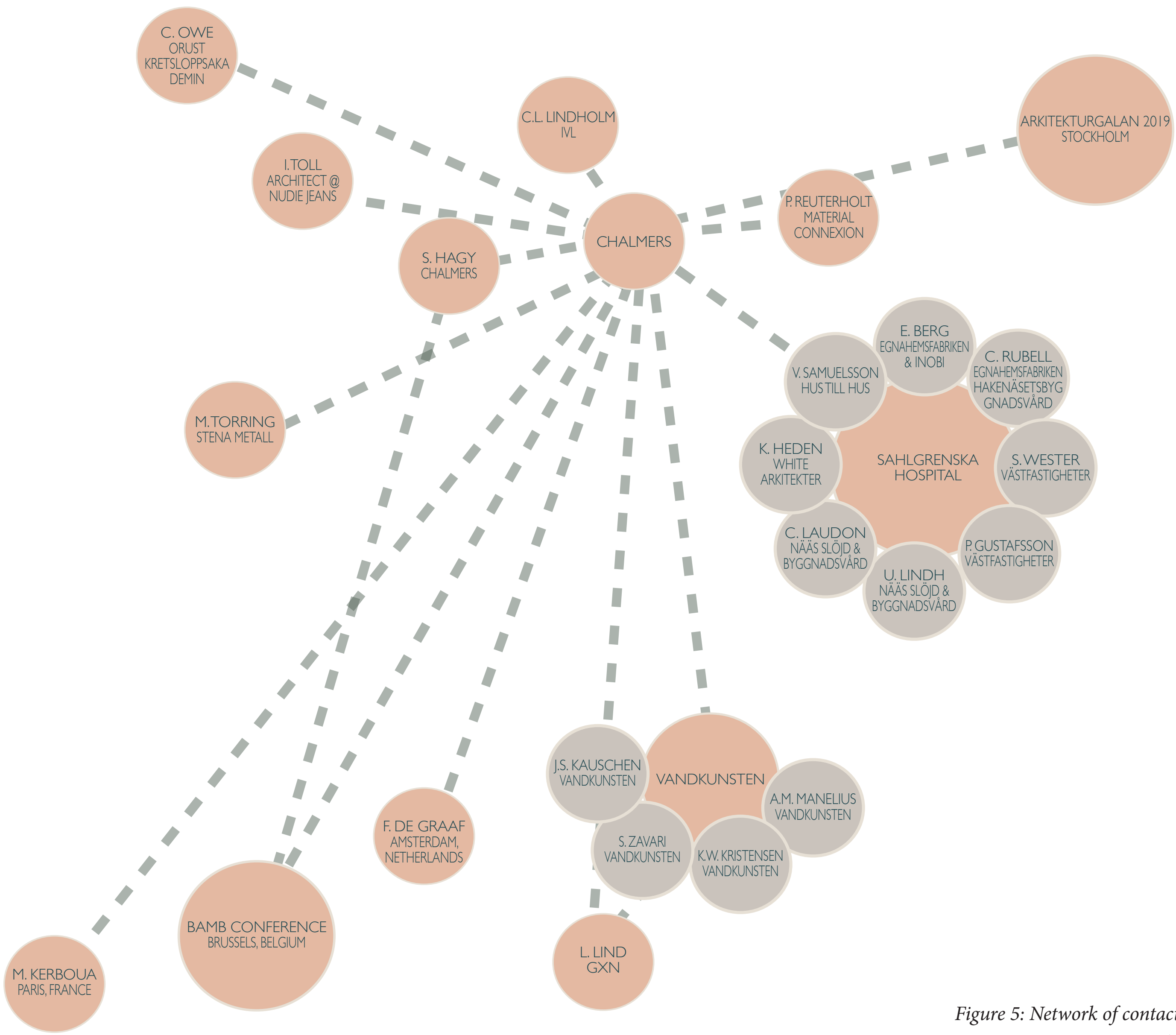


Figure 5: Network of contacts

DELIMITATIONS

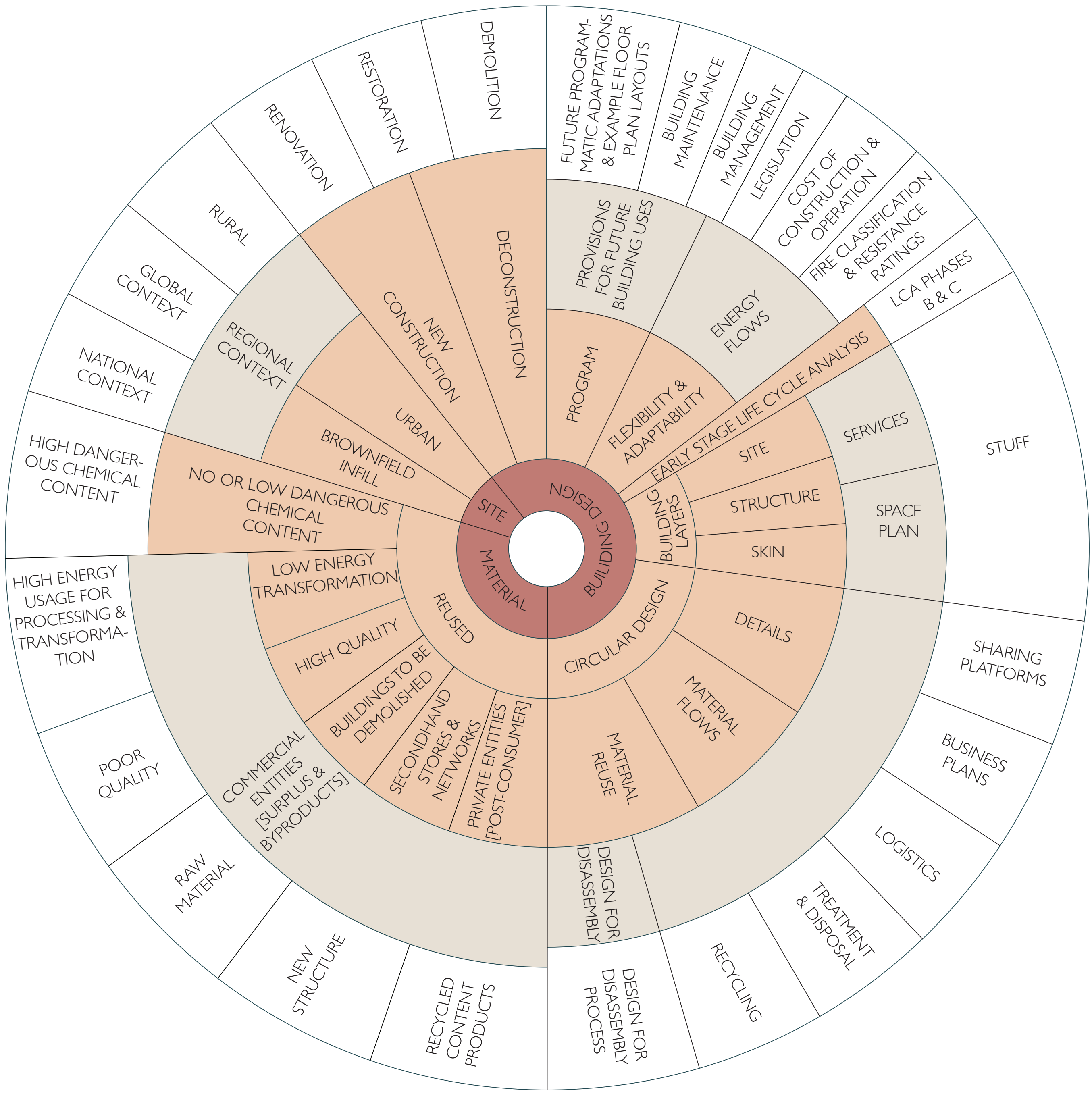


Figure 6: Delimitations

KEY

	Category	Topic
Main Focus	■	■
Included but Marginal Investigation Focus	■	
Beyond Investigation Boundaries	□	

The delimitations of this thesis investigation are shown in the diagram above. The main themes are building design, reused material, and a local context. The discussion is then how the topics inform and are related to one another, affecting the system within which they operate, and ultimately shaping the built environment. That which is included in the focus area is within the author's area of study and experience.

The topics shown outside of the focus boundary are acknowledged as affecting the topics included in the investigation but are too broad for this thesis, which is limited by time and the expertise of the author. For example, while circular design may be carried out by an architect, the "how" of systemic change to support a circular economy should be left to experts working with logistics and business plans.

TERMS & DEFINITIONS

BUILT ENVIRONMENT

That which humans create themselves

BY-PRODUCT

"A secondary product derived from a manufacturing process or chemical reaction. It is not the primary product or service being produced." ("By-product," 2019)

DECONSTRUCTION

"The selective dismantlement of building components, specifically for re-use, repurposing, recycling, and waste management." ("Deconstruction," 2019)

DEMOLITION

"Where a site is cleared of its building by the most expedient means" ("Demolition," 2019)

DISASSEMBLY

*See deconstruction

DOWNCYCLING

When a product is recycled but loses quality in the process. (Röstlund, 2017)

EMBODIED ENERGY

Energy sequestered in buildings and the materials of which they are composed, often calculated using life cycle analysis tools.

MATERIAL FLOW ANALYSIS (MFA)

"A tool to quantify the flows and stocks of materials in arbitrarily complex systems. MFA has been widely applied to material systems in providing useful information regarding the patterns of resource use and the losses of materials entering the environment."
(Laner & Rechberger, 2016)

MATERIAL PASSPORT

Circular data set initiative: a "document consisting of all the materials included in a product or construction. It consists of a set of data describing defined characteristics of materials in products, which give them value for recovery, recycling and re-use." ("Material Passport," 2019)

PRE-CONSUMER RECYCLING

"The reclamation of waste materials that were created during the process of manufacturing or delivering goods prior to their delivery to a consumer." ("Pre-Consumer Recycling," 2019)

POST-CONSUMER WASTE

"A waste type produced by the end consumer of a material stream; that is, where the waste-producing use did not involve the production of another product." ("Post-Consumer Waste," 2019)

RECYCLING

"Recycling is the process of converting waste materials into new materials and objects. It is an alternative to "conventional" waste disposal that can save material and help lower greenhouse gas emissions. Recycling can prevent the waste of potentially useful materials and reduce the consumption of fresh raw materials, thereby reducing: energy usage, air pollution (from incineration), and water pollution (from landfilling)." ("Recycling," 2019)

REUSE

To reapply or reinstall a material (post-consumer, by-product, waste) in the same manner as originally intended or for a useful new application.

REVERSIBLE BUILDING

Transformation capacity at a building level and reuse potential at a product level. 3 categories: irreversible, partly reversible, & reversible.

SUSTAINABLE DEVELOPMENT

"In essence, sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development; and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations."
(Brundtland Commission, 1987)

UPCYCLING

"Waste has the potential to become new materials or products with a higher utility value." (Lendager, 2018)

READING INSTRUCTIONS

This thesis investigates material reuse as a method for reducing the construction industry's negative environmental impact on a variety of scales, from the global to the local, in six parts:

PART ONE: INTRODUCTION

The first chapter states the author's motivations for the work, the background of the investigation, goals, and the thesis delimitations.

PART TWO: CONTEXT & CONCEPTS

The second chapter discusses theory related to sustainability and material waste, as well as the global, national and local contexts within which this thesis is situated.

PART THREE: CASE STUDY

The third chapter introduces the case study in which the theory and methods from the research stage in Part Two are tested through design in the local context of Mariestad, Sweden.

PART FOUR: FINAL DESIGN PROPOSAL

The fourth chapter visualizes the final design proposal, born from the case study process and design development in Part Three.

PART FIVE: EVALUATION

The fifth chapter objectively evaluates the building design proposal results, the pros and cons of designing with and for reuse, and the systemic changes needed to implement material reuse on a wide scale.

PART SIX: CONCLUSION & REFLECTION

The sixth chapter concludes the thesis, relating the findings back to the original research questions.

READER'S WAY-FINDING ICON

The reader may use the below icon to identify which sections of text throughout the thesis report pertain to the larger system, and therefore the broader discussion on waste and material reuse, within which this investigation takes place.

See page 28 for the description of the system as a tool for understanding the complexities and relationships of the building industry, architecture, and outside influences.

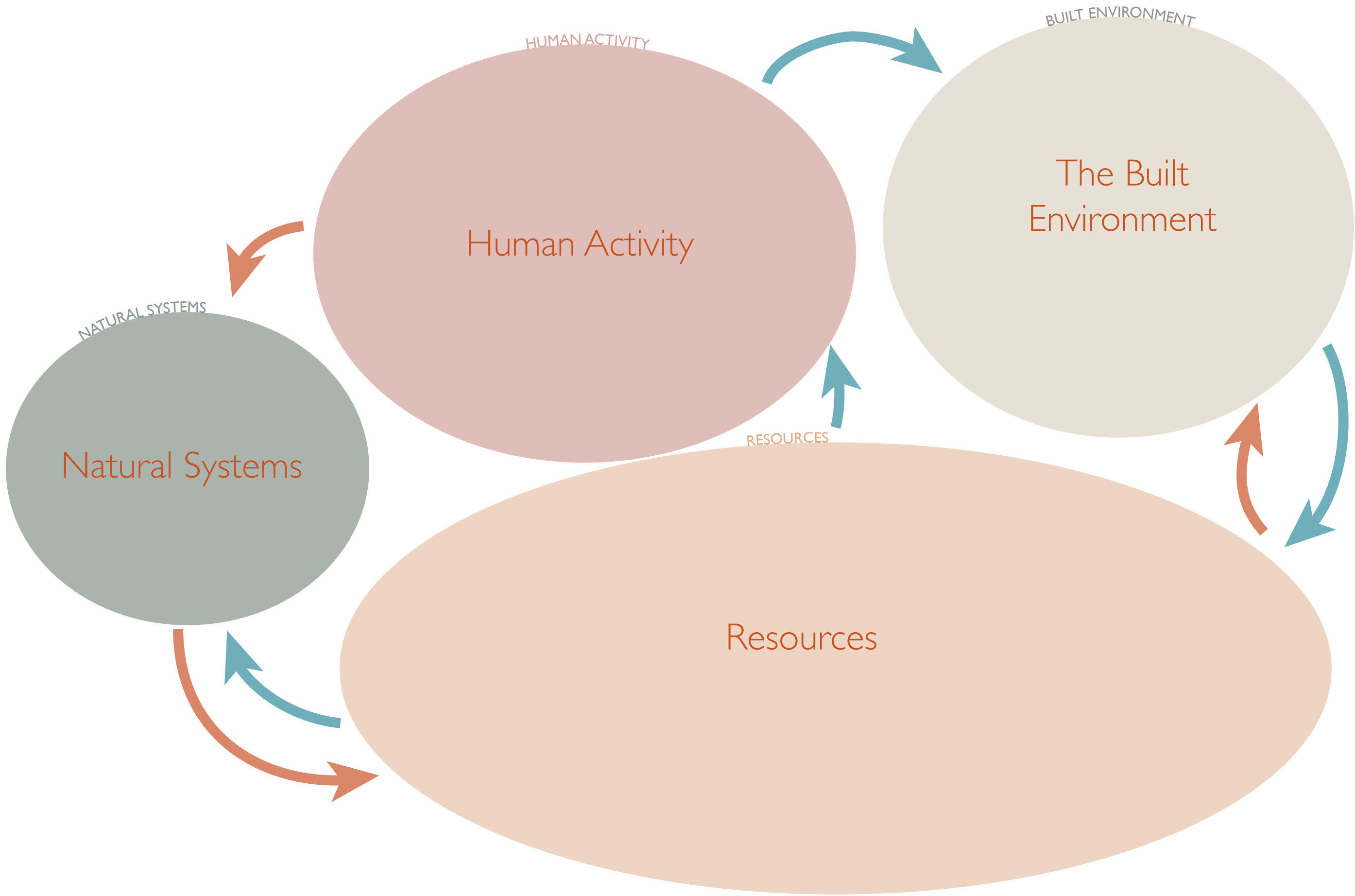


Figure 7: Simplified Existing System

Landfill City: where will all of the waste go?

Figure 8: A waste landscape sketch inspired by the 2006 film, Idiocracy's (Judge et al.); a comical representation of dystopia, which is becoming all too real

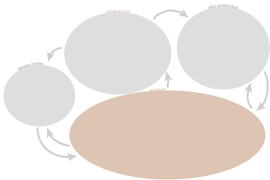
PART TWO

Theory

Waste -
Resource / Waste Management -
Cultural -
Consumption -
Economic -
Circular Design -
Building & Material Lifetime -
Systems Design Approach -

Context

Existing Conditions



THEORY

WASTE

WHAT?

"'Waste' means any substance or object which the holder discards or intends or is required to discard." (EU Waste Framework Directive 2008/98/EC)

"The notion of waste is relative in two main respects. First, something becomes waste when it loses its primary function for the user. A waste is therefore relative to this primary function. However, and this is the second perspective, what is considered waste with regard to this primary function may be useful for a secondary function. In other words, somebody's waste is often somebody else's (secondary) raw material." (Bontoux and Leone, 1997, p. 8)

Given the two definitions provided above, it is difficult to pinpoint an exact definition of waste. This text discusses "waste" in recognition of the EU's definition of the term but also recognizes that the discarded material likely still holds value dependent on how it is perceived, processed after its first (or other) use, and potential functions.

Figure 9 to the right diagrams the various types of waste. Primary focus is placed on the outlined items, while secondary focus is placed on those which are solely highlighted.

WHY?

Building waste is caused by a confluence of design error, economic factors, and cultural perception. Building vacancy and constant refurbishment indicate a lack of adaptability and inability to meet changing programmatic and usage needs.

During demolition and renovation processes, it becomes clear that buildings are not designed to be disassembled into reusable parts given the difficulty of separating and removing materials as whole, valuable pieces. Economically, many are focused on the immediate investment cost and short-term gains; oftentimes, the monetary cost is less when demolishing buildings and rebuilding to maximize the allowable building area (to maximize profit) than keeping and renovating older buildings. Culturally, societal perceptions of beauty and attractiveness change over time; the perception of a building as "ugly" reduces its value.

REUSE: LEGAL IMPLICATIONS

"The legal definition of reuse according to the Swedish Ordinance of Waste (2011:927):

'Reuse is defined as something that is not waste and used again to fulfill the same purpose. Thus, legally a product or material is only reused if it serves the exact same function.' (Wilder, 2017, p. 16)

This is a narrow definition that could create regulation issues for those interested in adapting materials for new uses." (Jonasson, Josefsson, & Marklund, 2019, p 14)

While the legality of material reuse must be taken into account in real-life applications, this thesis is focused on the reuse possibilities of waste products, as well as items meeting the legal definition of reuse, rather than the limits of the law.

A QUESTION OF OWNERSHIP

"The existing linear system of material flows is very complex. The moment a product or material is officially disposed of, for example at a recycling center, it is owned by someone other than the individual or entity that disposed of it. While there is a vast amount of usable, non-hazardous material that could be used after its first life, the question of ownership and the process that follows disposal creates a large barrier for potential material salvaging and reuse."
- (Jonasson, Josefsson, & Marklund, 2019, p. 14)

HOW DO WE REDUCE BUILDING WASTE?

In order to reduce building waste, how buildings are designed, the cultural stigma against the value of used materials, legislation, the logistics of the construction industry and material flow system, and transparency of information must all change. All levels of circular and sustainable decision-making require appropriate amounts of information in the form of material passports and life cycle analyses.

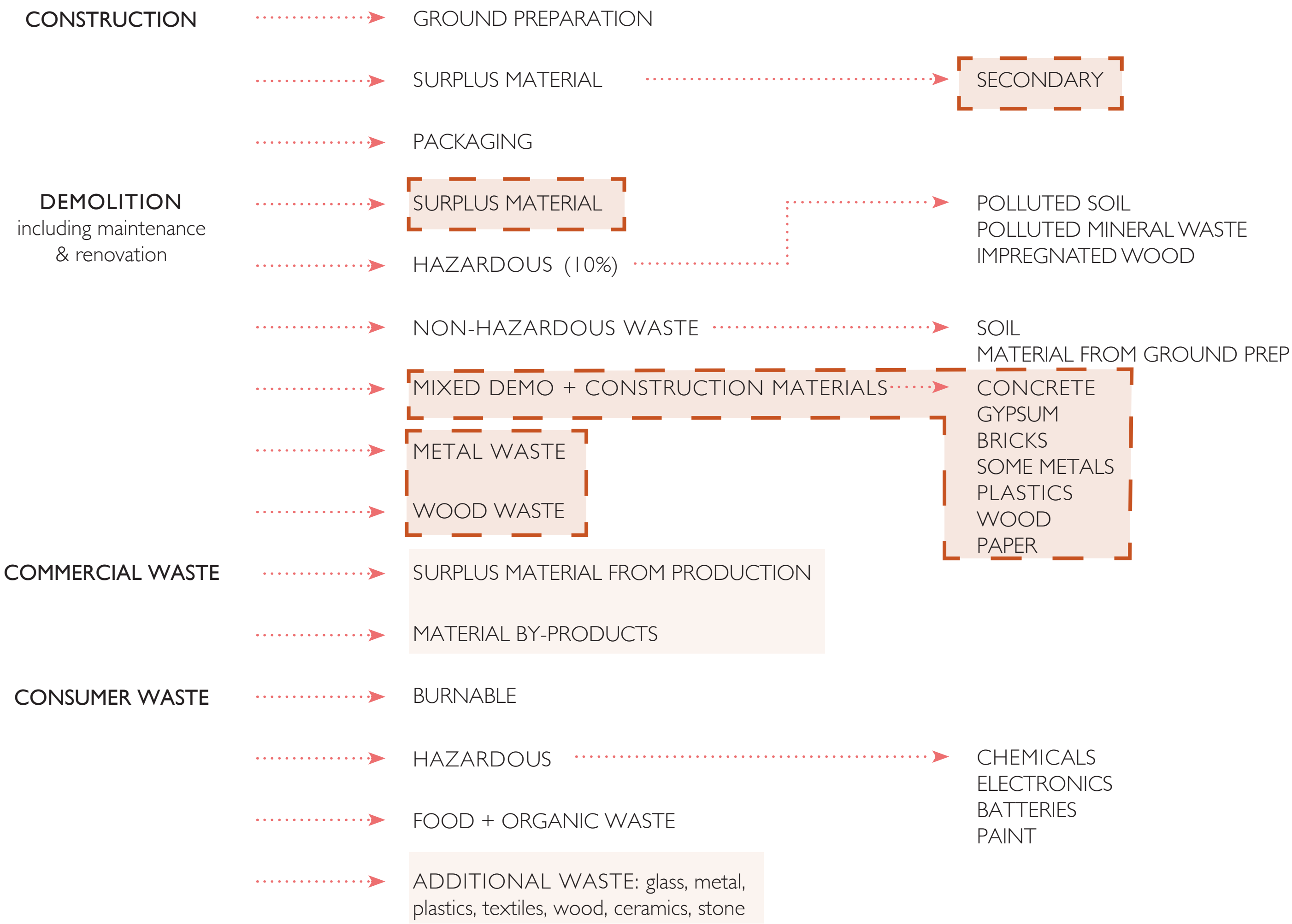
"If material is to enter into a circular economy, it must be made possible to:

1. Prevent the disposal of material by the original owners.
2. Intercept material to be disposed of prior to reaching a disposal or recycling center.
3. Make material available to be purchased by subsequent owners (from recycling centers, recycling companies, etc.)"

- (Jonasson, Josefsson, & Marklund, 2019, p. 14)

WASTE DIAGRAM

Figure 9: Waste Diagram (Jonasson, Josefsson & Marklund, 2019)



~~WASTE~~ RESOURCE MANAGEMENT HIERARCHY

The Delft ladder is a waste management strategy adopted in the city of Delft, Netherlands (Kowalczyk, 2000) and is consistent with EU policy (2008/98/EC), as well as national Swedish waste management policies. The method organizes building materials in a hierarchy, in order from the best to the worst methods of material reuse & processing. The diagram to the right is a diagrammatic adaptation of Delft's waste management strategy.

This thesis focuses on steps 3-5, as indicated with an asterisk*

"The requirement for a well-designed waste management system should form a fundamental part of the design and planning process because 80% of all environmental costs are predetermined during the conception and design phase of the project."
- Baker-Brown, 2017

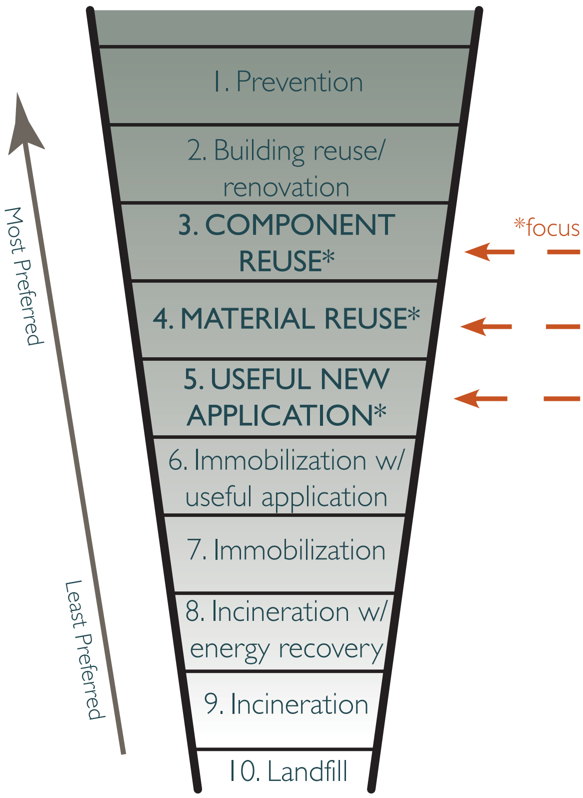
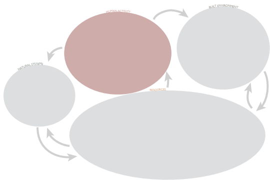


Figure 10: Adaptation of the Delft Ladder (Kowalczyk, 2000)



CULTURAL

An interesting dichotomy exists between the perceived values of "old" buildings, materials, and things from classical or historical eras and those existing from the modern era. Very old (approximately +50 or +100 years) buildings are highly regarded as symbols of historical significance and beauty, even if they nowadays function solely as monuments. On the other hand, buildings from the 80s and 90s, such as the typical American office park, which were designed according to the trends of the time and employed developing materials and technologies are often considered tear-downs. These buildings with lives of 20-40 years are regarded as disposable, holding little value and are therefore not loved.

Culturally, societal perceptions of beauty and attractiveness change over time; the perception of a building as "ugly" reduces its value. Strangely, the older a building is, the more historical and aesthetic value it holds, while goods and designs that can clearly be linked to more recent trends and fashions are now considered out of vogue, ultimately generating dislike and losing monetary value.

The cultural stigma against that which is perceived to be "old" or "used" from the last few decades is a fairly new phenomenon. Throughout history, building materials have been salvaged and re-purposed in new construction or renovation. Two historically significant examples include *spolia* from the Roman times and the Mezquita de Córdoba in Spain.

In the report by the Danish architecture firm Vandkunsten, *Rebeauty: Nordic Built Component Reuse* (2016), the firm argues that "without beauty, there will be no sustainability." In summary of a discussion with Anne-Mette Manelius, Katrine West Kristensen, Salma Zavari, and Jan Schipull Kauschen of Vandkunsten (personal communication, March 5, 2019):

"The cultural values related to reused materials are high; recognizable building components that were previously part of the city's built identity can be incorporated into new structures, forming an interesting narrative and linking the new building to a place's history. It is important to incorporate the reused materials in a beautiful way; humans are attracted to beauty.

The story (of a material or component) increases the cultural value and even increases the lifetime of the building. When people develop a connection to their built environment, they want to protect it, in essence extending a building's lifetime, increasing its sustainability. The first role of sustainability is to build something that no one will want to tear down.

How do you quantify the non-qualitative elements of architecture (i.e. benefits of beauty, story, etc.)? These qualities can be marketed to make a building more attractive and can ultimately translate into economic benefit."

Not all beauty lies in perfection, as one might think from the prevalence of stark white modern interiors in design photography. To quote Mark Gorgolewski "How do we convince society to accept imperfection?" (BAMB conference lecture, February 6, 2019). If material perfection were not the gold standard, people would be more open to continuing to use buildings and items owned for a number of years, or even to buy materials secondhand. The Japanese concept of *wabi-sabi* embraces this idea, challenging the notion of perfection as the equivalent of beauty.

"Wabi-sabi is the beauty of things imperfect, impermanent, and incomplete, the antithesis of our classical Western notion of beauty as something perfect, enduring, and monumental." (Koren, 1994)

To promote circularity through material reuse, value culture must be changed. Rather than see goods, materials, and buildings as disposable and having little value due to their age or the fashionability of their aesthetics, society should learn to see their future potential. A new application, a renovation, or fixing a broken item can not only increase its value, but can also add to its history, or story. It can extend the material's life, preventing it from designation as waste and reducing the need for new, raw resources to fill its place. Architects and designers are responsible for creating beautiful, desirable goods, spaces, and buildings to provide society with a chance to love those same things, take care of them, and thereby be more sustainable.

Figure 11: Columns in the Mezquita de Córdoba, Spain, originated from various locations throughout Iberia (August 2017)

CONSUMPTION

Figure 12: Marble Quarry
Virginia, USA (Choi, February 2019)

People living in Westernized cultures have been conditioned to consume: the more up to date one is, or the more one has of the latest and flashiest trends, the higher his or her status. Trends move quickly; with increasing speed, people are persuaded to buy and discard products with that same speed. The fashion of yesterday is looked down upon, losing cultural value (and therefore economic value), when in reality, the physical value of the material has not changed. This trend of consumerism applies to the majority of material goods, from H&M's 52 clothing seasons (Morgan et al., 2015) to design influencers' seasonal homes and interiors.

With trends moving at such a fast pace, bank accounts cannot keep up if consumers are to purchase new goods of high quality at appropriate prices, equal to the cost of the material, labor, embodied energy, and environmental impact. Consequently, purchasers are enticed by the low prices of poor quality products. These are often priced below their actual value as they have been produced by underpaid labor, while the environmental costs are absorbed by the place of resource extraction and material processing, out of sight of the consumer. With low prices, the consumers are barely impacted but, are, in fact, convenienced when able to discard cheap items at a whim and replace them with newer, on-trend goods. Without proper logistics for reuse, recycling, or disposal of the post-consumer goods, much of this material is designated as waste and dumped as landfill, incinerated for energy recovery, or is exported elsewhere.

The consumption of buildings themselves is not as fast-paced as in fashion, but the consumption of interior decoration is on this track. While new construction and building renovation costs a great deal, the cost is reduced by using cheap, low-quality materials, which wear down quickly and reduce the lifetime of buildings, perpetuating the cycle of consumption. It is more fashionable to discard the old and build with new every 5, 10, or 20 years than to invest in good quality materials and buildings that will endure in the long-term.

ECONOMICS

In the current Western model, society is driven by economics. Economic growth is equal to success of an individual, company, or country. It is difficult to argue against those with this mindset when a linear material flow based on production, use, and disposal has led to economic growth up until this point. When stepping back and looking at the larger picture, it becomes clear that there will be an end to this economic growth if resources are consumed to the point of extinction: continued growth is neither sustainable nor even possible.

However, keeping in mind that money is a driving force, there are plenty of opportunities for businesses to invest in sustainable, circular practices. To change the status quo of the construction industry and its perpetuation of the linear materials flow, new forms of logistics must be put in place, requiring new business models and the education of the labor force, among other things. While such changes require significant investment, environmentally sustainable business models will be economically sustainable in the long term.

As understood from architects working with material reuse, today there is currently no economic argument for reuse given the lack of tested methods and logistics framework.

CIRCULAR DESIGN

"The circular economy is one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technological and biological cycles. This new economic model seeks to ultimately decouple global economic development from finite resource consumption. It enables key policy objectives such as generating economic growth, creating jobs, and reducing environmental impacts, including carbon emissions."
- Ellen MacArthur Foundation, 2015

"Employing circular thinking in the design and the construction industry can significantly reduce the industry's climate change and emissions impacts in addition to reducing waste, conserving resources, increasing local employment and skills, and strengthening local economy (Gorgolewski, 2018).

The diagram below shows how materials in a circular design could flow; the majority of the material in the system circulates continuously, while only a minimal amount of unusable and / or dangerous materials is removed from the system for incineration or energy recovery as a last resort." (Jonasson, Josefsson, & Marklund, 2019, p. 13)

Circularity increases the useful life of existing materials, preventing or minimizing the need for new raw materials and the energy required to extract, produce, and transport them.

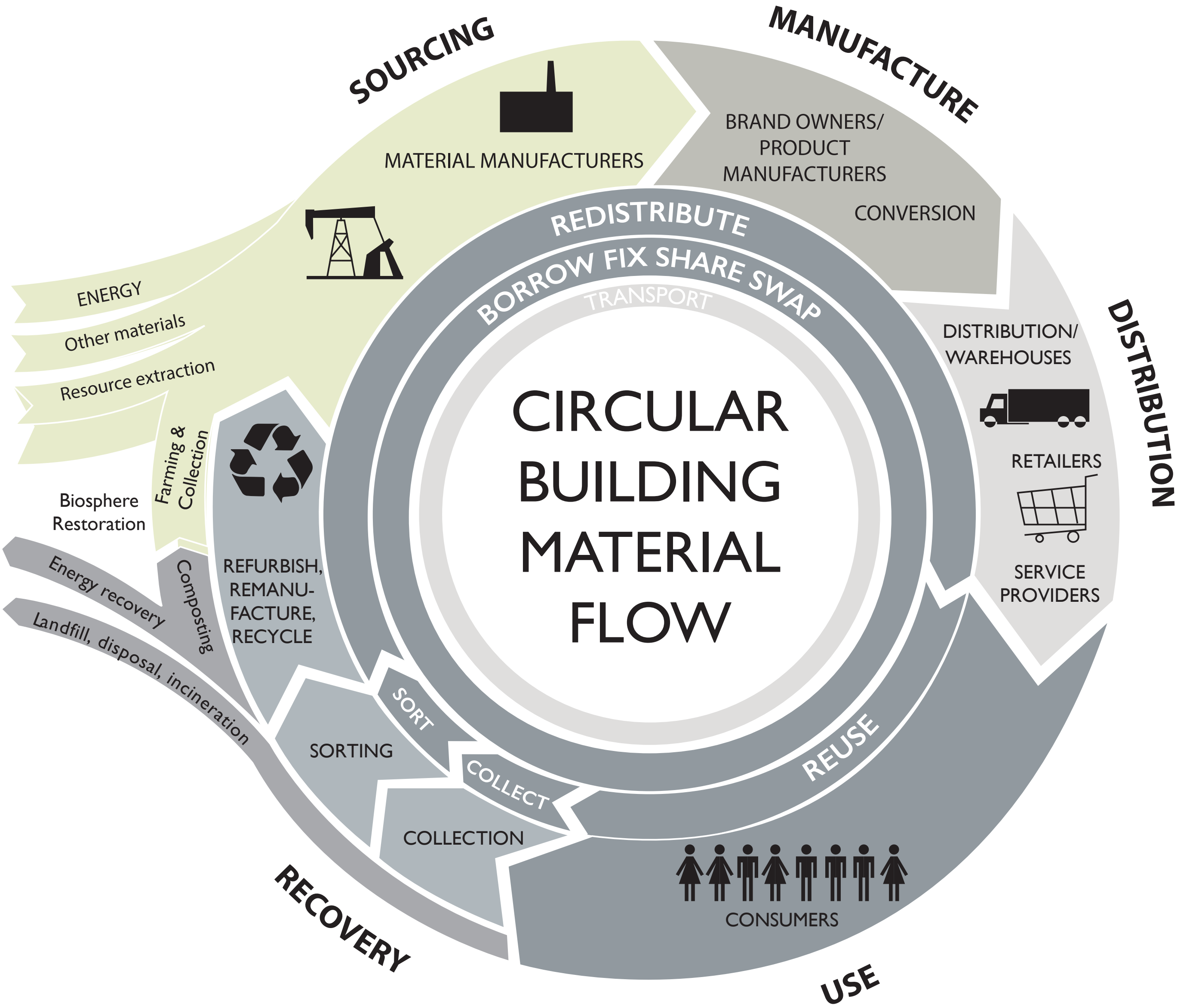


Figure 13: Circular Design
(Adapted from Jonasson, Josefsson & Marklund, 2019)

BUILDING & MATERIAL LIFETIME

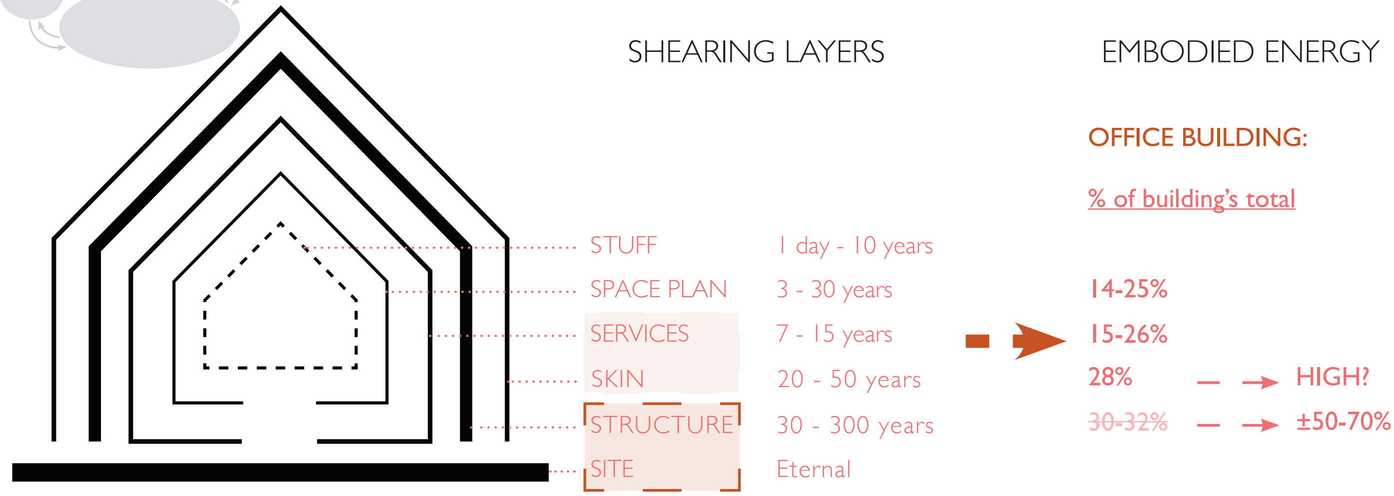


Figure 14: Shearing Layers (Brand, 1994) w/ embodied energies (Crowther, 2015)

Shearing Layers, shown in Figure 14 above, is a concept first coined by Frank Duffy and later elaborated by Stewart Brand (1994). The following definitions are reproduced from Brand (1994):

"Site

The geographical setting, the urban location, and the legally defined lot, whose boundaries and context outlast generations of ephemeral buildings.

Structure

The foundation and load-bearing elements are perilous and expensive to change, so people don't. These are the building. Structural life ranges from 30-300 years (but few buildings make it past 60 for other reasons).

Skin

Exterior services now change every 20 years or so to keep up with fashion or technology or for repair. Recent focus on energy costs has led to re-engineered skins that are air-tight and better-insulated.

Services

Communications wiring, electrical wiring, plumbing, fire sprinkler systems, HVAC, and moving parts like elevators and escalators. Many buildings are demolished early if their outdated systems are too deeply embedded to be replaced easily.

Space Plan

The interior layout - walls, ceilings, and doors. Turbulent commercial space can change every three years or so; exceptionally quite homes might wait 30 years.

Stuff

Chairs, desks, phones, pictures; kitchen appliances, lamps, hairbrushes; all of the things that move around daily to monthly."

While the difference between the expected lifetimes of building layers is significant, they are often not designed for maintenance; the ability to efficiently access, disassemble, and maintain the separate layers is necessary to lengthen the building's lifetime. Additionally, many buildings are demolished prior the end of their useful or expected lives due to the economic and cultural reasons previously stated.

EMBODIED ENERGY OF BUILDINGS & THEIR MATERIALS

"The embodied energy of a material or product is the sum of all the energy required to produce that material or product. This will include the energy required for: materials extraction, materials processing, transport and direct manufacturing. It also includes part of the energy required to create the buildings and machinery associated with all these steps in processing" (Crowther, 2015). The embodied energy of a building or material is calculated with life cycle analysis; while energy studies provide varying values, proving that it is difficult to determine exact embodied energy figures, LCA's are used as benchmarks by which a building's environmental impact may be measured. The embodied energy of a building can be higher and more environmentally significant than the operational energy of a building during its lifetime, as building operational energy use is becoming increasingly efficient in recent new construction (Stauffer, 2009).

The embodied energy of a building's materials contributes a numerical significance to its value. With the energetic value of the materials in mind, the importance of their maintenance and continued circulation in the system becomes clear. By discarding materials before the end of their useful lives, one not only generates unnecessary waste but wastes their embodied energies. The table below shows the estimated percentages of embodied energy of various office building layers, per Crowther (2015); however, these numbers vary depending on the materials used. It is the author's opinion that Crowther's structural percentage estimate is low. The structure likely constitutes 50-70% if a light skin is used.

Building Layers				Building Type
Structure	Skin	Services	Space	
30-32%	28%	15-26%	14-25%	Office

Figure 15: Percentage of Embodied Energy by Building Layer (Crowther, 2015)

SYSTEMS DESIGN

SYSTEMS THEORY

Systems theory is the science of interconnectedness. Everything is connected; simplicity turns into complexity, and all of the system elements are affected by an underlying principle of unpredictability.

Systems thinking is a useful tool for designers to understand complex issues. A system is an instrument of rationality that can expose or explain how things are connected and the nature of their connections. Within systems, one can establish hierarchies, organized within boundaries. The designer of the system defines the boundaries. Based on the system designer's world view and agenda, the system is presented in a certain way and can be manipulated as an idealogical tool.

SYSTEMS DESIGN AS A TOOL FOR INVESTIGATION

In this thesis, systems design tools have been modified to suit the needs of the author, an architectural designer, to make sense of the chosen system elements from which it has been possible to pinpoint problems and propose solutions. In understanding the political, social, and environmental impacts of a project, one may apply a holistic approach to the work.

These tools have provided an understanding of how the construction industry's operations affect the environment on the global, regional, and local level, as well as the variables of the system (and their hierarchical relationships) that are affected by an architect's decisions. In identifying the system of interest, its boundaries, and problems (as related to environmental degradation), it is possible to propose solutions by finding system leverage points at which to intervene and understanding the effects and reactions that will ensue. The goal of introducing these interventions is the reduction of the construction industry's negative environmental impact through implementation of material reuse in a circular economy.

The proposed interventions and vision for a future system that supports material reuse are found in the Part Five Evaluation chapter.

DIAGRAM DESCRIPTIONS

In Figure 16 below, the diagram shows a simplified version of sub-systems of the larger system context within which this thesis is situated. Throughout the thesis report, the diagram will be used as a map to situate the reader in the context, clarifying its complex nature.

In Figure 17 to the right, a more complex version of the same system is illustrated. Important system elements and their relationships are shown.

DEFINITIONS

(P. Wallman, personal communication, January 18, 2018)
Reinforcing Relationships (+/blue): Something that causes a condition to amplify.
Ex. putting wood on a fire cause more fire to burn and spread

Balancing Relationships (-/red): Something that causes a changes which dampens (oppose) a condition.
Ex. putting a water on a fire stops it from spreading

The Simplified Existing System

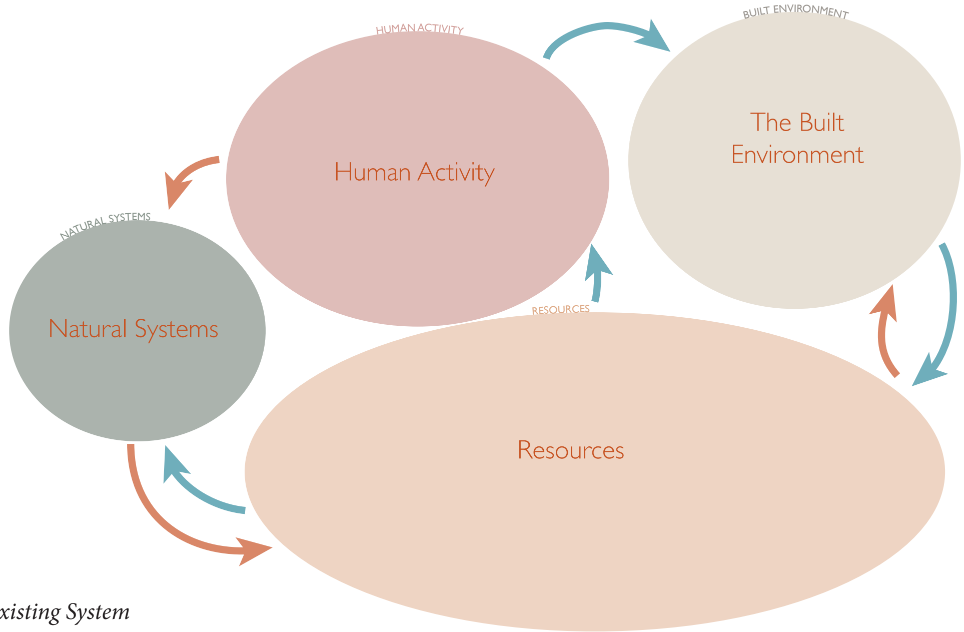


Figure 16: Simplified Existing System

The Existing System

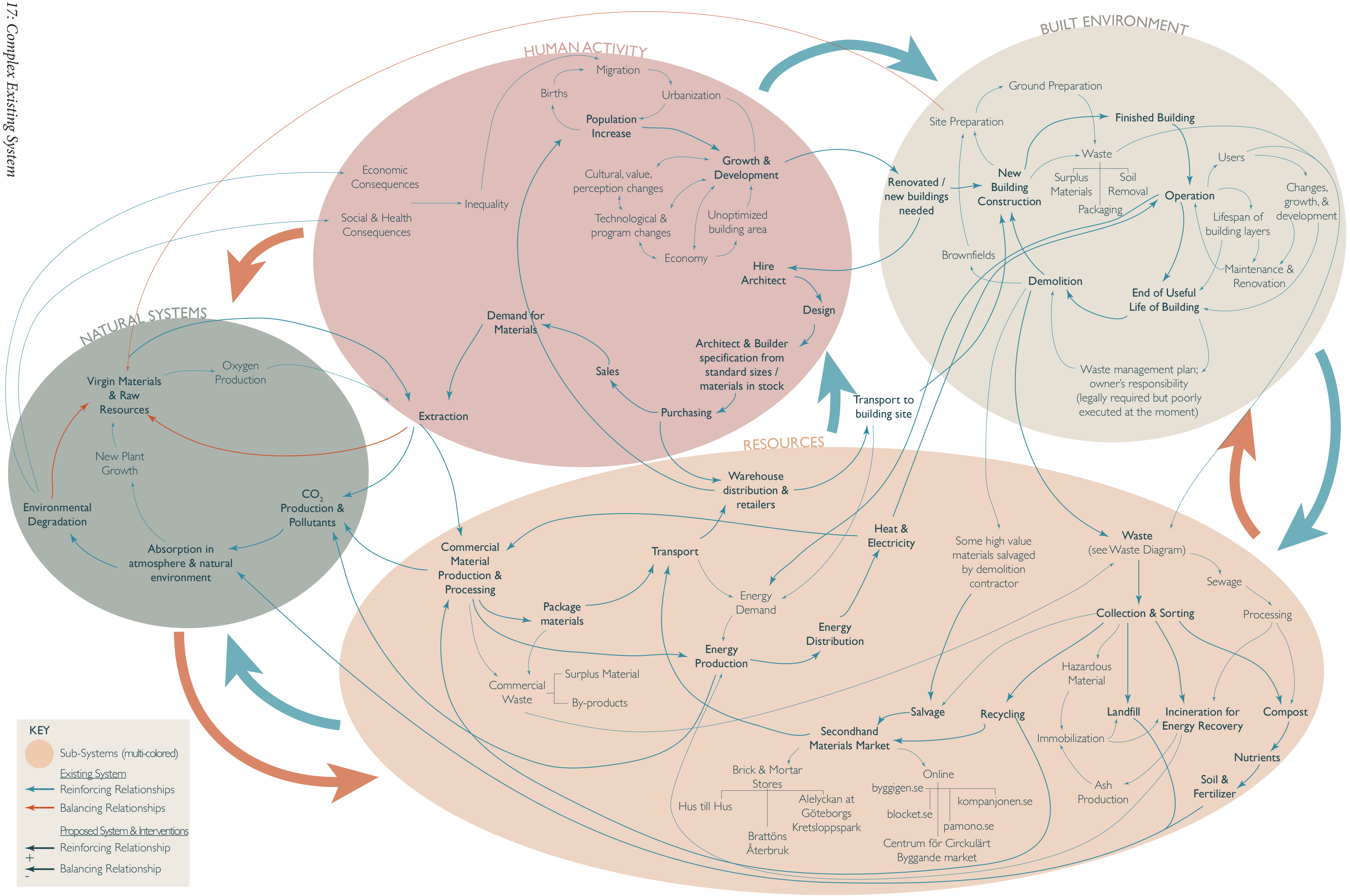


Figure 17: Complex Existing System

CONTEXT

FROM GLOBAL TO LOCAL

The EU & Sweden committed to

70% reuse, recycling & other recovery of construction and demolition waste by 2020

+ self-sufficiency in waste management, waste management hierarchy, & waste prevention programs

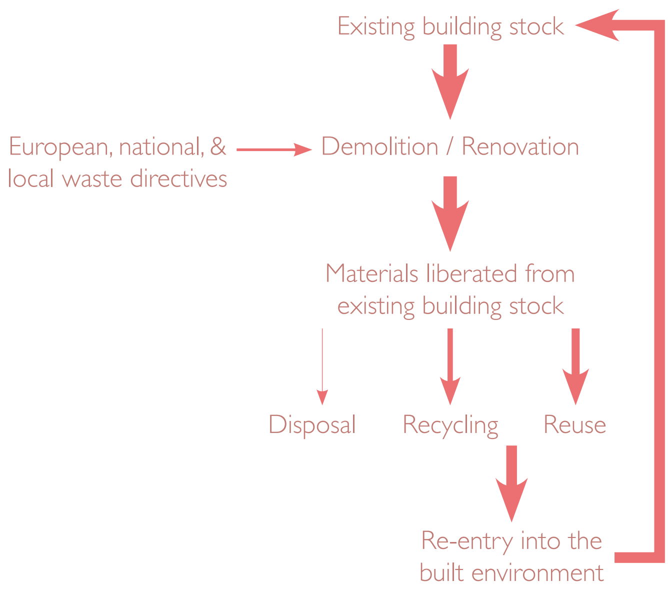


Figure 18
With the waste management directives in place, companies and individuals will be more likely to make used materials available for reuse. The thicker the arrow, the higher the material flow volume.

GLOBAL

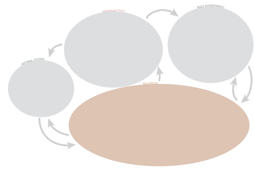
High income countries, large corporations, and wealthy individuals are those who contribute the most to resource over-consumption, greenhouse gas emissions, pollution, and ultimately, climate change. It is often the less-developed countries that must bear the brunt of the negative environmental impact of wealthy, developed countries who often export their emissions and waste to poorer areas to be handled by cheap labor or to dumped in "unseen" places (Althor, 2016). Sector-wise, the construction industry is responsible for over 30% of global resource use (UNEP, 2011).While high levels of environmental degradation are occurring at the expense of poorer people, the effects have gone largely unnoticed by the wealthier nations, until recently when increased migration, higher temperatures, and altered weather patterns have affected the everyday lives of people in the HIC nations.

CONTINENTAL: EUROPE

In the EU, the building and mineral extraction sectors account for 63% of the EU's waste production (Naturvårdsverket, 2018). The EU has put in place a number of directives to curb the disproportionate amount of natural resources consumed, waste produced, and greenhouse gases emitted by the continent. One of these is the Waste Framework Directive (2008/98/EC), which establishes a need for self-sufficiency in waste management in the EU, a waste management hierarchy, and a 2020 target of 70% reuse, recycling, and recovery of construction and demolition waste. It requires Member States to adopt waste management plans and waste prevention programs. In addition to legislation promoting better waste management, a number of architecture firms and other companies, such as SuperUse Studios and Rotor Deconstruction, are promoting material reuse through practice as a strategy for waste management and climate impact reduction.

NATIONAL: SWEDEN

Sweden is taking strides towards decreased waste and more efficient material use through national legislation, municipal programs, and ground-up initiatives, although change is not progressing fast enough. Nationally, non-hazardous waste increased 15% (not including waste from the mining sector), while hazardous waste decreased 7% between 2014 to 2016 (Naturvårdsverket, 2018). The building sector is the largest contributor to waste production after the mining sector, producing 9.8 million tons in 2016. Naturvårdsverket has set a goal of reusing, recycling, or (other forms of) recovering 70% of the nation's non-hazardous construction and demolition waste by 2020.



LOCAL: THE CITY OF MARIESTAD

This thesis discovers the possibilities of working with material reuse in construction through a case study, based in Mariestad.

"The chosen site is the city of Mariestad, the capitol of Mariestad municipality. The city is located in the Västra Götaland region of central Sweden on Lake Vänern, Europe's largest lake. Mariestad is positioned halfway between Sweden's two largest cities, Stockholm and Gothenburg, along a major vehicular transportation route (highway E20) that connects the two.

The city of Mariestad (and the municipality as a whole) has undergone major changes in recent years due to a administrative reorganization of the (Västra Götaland) region, as well as being heavily impacted by trends on both the global and local levels, including an aging population, global migration, increasing urbanization, individualization, technological development, commercialization, and increasing greenhouse gas emissions. Some of these trends can be seen as threatening to the area, causing a decrease in the local population and services." (Jonasson, Josefsson, & Marklund, 2019, p 8)

While all of the trends listed above require attention, this investigation is focused on the environmental aspect. Mariestad requires action to strengthen its resilience against climate change. One ongoing initiative is its local municipal waste management plan. The plan outlines steps for reducing the municipality's waste production (Mariestad, 2019). The goal of waste reduction inherently requires reduced raw material consumption with the simultaneous increase of material reuse and recycling.

Select plan objectives and goals related to minimizing the impact of the building industry are laid out in Mariestad's waste management plan (Avfall Skaraborg, 2014):

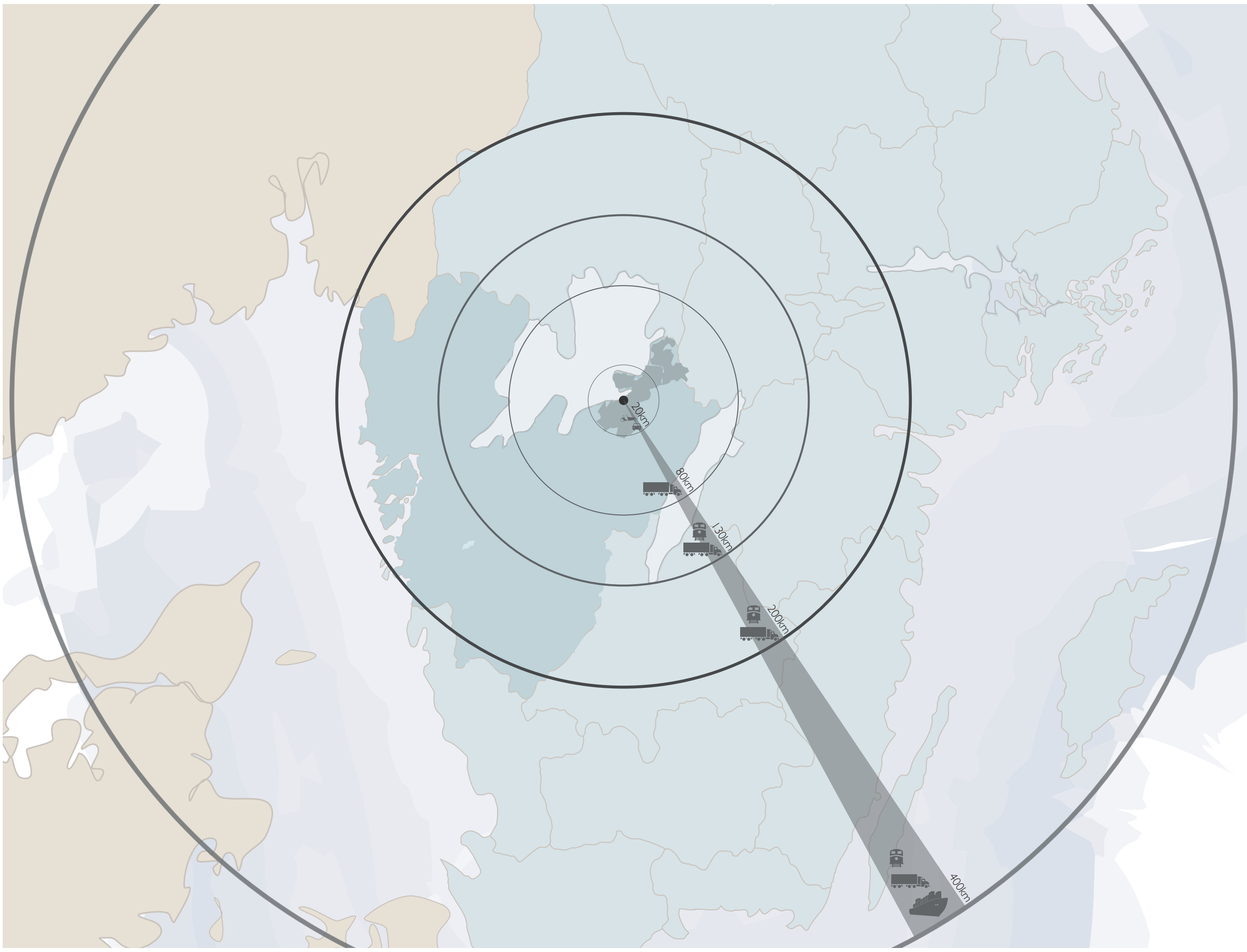
- Increased resource management in the construction sector. Efforts shall be made so that the preparation for reuse, recycling, and other recycling of non-hazardous building and demolition waste is at least 70% by 2020 at the latest.
- Use waste as a resource. Strategy: When the municipality or municipal company is rebuilding or building new, all construction waste is sorted by 2018 at the latest.
- Plan and collaborate for long-term sustainable waste management. Strategy: As of 2015, in all new buildings and major refurbishments, waste management, including work environment aspects, is taken into account in the initial planning phase, as well as in all subsequent steps.

The Swedish building sector produced

9.8 million tons

of waste in 2016

Figure 19
City of Mariestad, Sweden



WHAT ARE "LOCAL" RESOURCES?

Figure 20: Material Transport Distance

"The term 'local' is dependent on the context and the availability of the resource. It can refer to one's neighborhood, the municipality in which one is located, or the general region.

When referring to food and material that can be produced in the area one lives, local can be considered as coming from a closer range than when referring to special skills or knowledge. LEED's definition:

'Building materials or products that have been extracted, harvested or recovered as well as manufactured within 500 miles (approximately 800 km) of the project site for a minimum of 10% or 20%, based on cost of the total materials value' (Morton, 2013)."
- (Jonasson, Josefsson, & Marklund, 2019, p 8).

Most virgin building materials travel great distances, contributing to the materials' (and eventually the building's) embodied energy and impact on the climate. The use of local materials can help reduce the energy and emissions required for material transportation.

However, according to a report published in a collaboration between RISE, Swearea, & IDC, it is generally better to transport existing material and components for reuse than to produce and purchase entirely new material, even if such a material is locally sourced:

"Increased transport and warehouse storage resulting from the circular business concept have, as a rule, a minimal environmental impact. For products that are transported via land with regular trucks, typically effective transport is not the largest issue... In this project's example, one could drive an upholstered wood chair back and forth from Barcelona to Malmö with a diesel truck to 'eat up' the carbon footprint of a tripled usage time period" (translated by the author, Arvidsson, N., Bolin, L., Lindberg, S... Tööj, L., 2016, p. 20).

This thesis defines local as a ±200km radius from the project site location (the city of Mariestad), consisting primarily of the Västra Götaland region but also including parts of Jönköping, Östergötland, and Örebro. While closer is better, three of the existing secondhand building material retailers of southern Sweden are located within this 200km radius. Additionally, given the great speed and amount of construction activity taking place in Sweden's second largest city, Göteborg, it is logical that it is included within the local material sourcing boundary. These materials and components can be transported to the site via truck, car, or bike.

EXISTING CONDITIONS

EXISTING & FUTURE BUILDING STOCK

"In addition to the classification of material stocks (raw material cadastre for residential buildings), it is of central interest to identify future waste streams in order to forecast potential secondary raw materials, determine recovery strategies and control mechanisms. Furthermore, the supply of exploitable fractions must be matched with demand to identify the degree of self-sufficiency of selected areas in order to reduce the use of primary resources and necessary transports."
-Heinrich & Lang, 2019

GOTHENBURG, SWEDEN AS AN EXAMPLE

To effectively plan for increased resource and waste management in the future, it is necessary to understand the types of material, quantities, qualities, and times at which they will become available after the end of their primary uses as entire buildings or building layers. "The age class suggests which construction materials to expect for secondary use when buildings come to an end of their lifetime" (Gontia et al., 2019, p. 14). This knowledge is key when designing with reused materials: without knowing what is (or will become) available and when, it is nearly impossible to create a design, let alone scale up reuse as a typical practice in the construction industry. Such information will also aid the logistical end of the material reuse industry in planning for deconstruction techniques and dates, post-deconstruction processing, storage, and redistribution.

However, Gontia et al. (2019) also note:
"The end-of-life of buildings is nevertheless a very complex matter, and in most cases the designed lifetime is not an appropriate indicator. For instance, in the case of China, it was shown that internal factors (e.g., construction quality, building type, etc.) have much less influence over the end-of-life of buildings when compared to external factors such as the economic context (Liu et al. 2014)."

As seen in the table below, buildings contain the majority of the existing material stock in use, and are therefore reliable sources for material mining.

Material Stock in Use	
Total:	84 million tons
% of Built Environment Component	
Buildings:	73%
Road Transportation:	26%
Pipes:	1%
% of Material Type	
Mineral Binding Materials (ex. concrete):	48%
Stone & Aggregates:	20%
Ceramics & Brick:	10%
Asphalt:	9%
Steel:	7%
Wood:	3%
Age Distribution of in-use Material Stock	
1960's-70's	40%
Other decades	avg. of 8% each
Before 1920	3%

Figure 21
(Gontia et al., 2019)

POPULATION GROWTH: PREDICTING FUTURE BUILDING NEEDS

In understanding how and when the population of a particular location will change, the amount and types of built environments required to support such changes may be predicted. Such predictions, in combination with efficiency of building resource and waste management, will allow for future needs for the built environment to be met.

The population of Northern Europe is expected to expand as a result of a variety of factors, including climate change. In an article in *Göteborgs Posten* written by the regional director of Sveriges Byggindustrier (Sweden's Building Industries), Göteborg is expected to become home to 1.2 million inhabitants by 2035 (currently over 1 million in 2019), mostly due to young people moving to the city and anticipated immigration. Sweden as a whole is expected to reach 11 million inhabitants in the coming years (currently at about 10,037,000). The building industry is already taking action to increase housing and infrastructure for the existing back-log of people waiting for housing, in addition to preparing for future needs (Lundbäck, 2019).

Länstyrelsen, the Country Administrative Board of Västra Götaland within which both Göteborg and Mariestad are located, has determined that the region requires 7800 additional homes to be built per year due to population increase. Mariestad's municipality anticipates population growth in one of two scenarios. In the first, population trends show that the population will grow by 500 inhabitants by 2025. In the second, the municipal goal is to reach 4000 new inhabitants by 2025, which is a number based on Boverket's (the Swedish national board of housing, building and planning) housing analysis. Both scenarios require an increase in housing, jobs, and infrastructure to support a growing population (Mariestad, 2018).

PART THREE

THE SITE

MARIESTAD, SWEDEN

INTRODUCTION

"This case study, located in Mariestad, Sweden, is a place-specific proposal that provides one example of how the construction industry, a top contributor to climate change, can reduce waste, embodied energy of a building, and add to a place's cultural identity by reusing materials in a new urban infill project. In grounding the proposal in a specific place and building on existing characteristics, the proposal shows how local conditions can contribute to a successful sustainability strategy.

While it is not possible to replicate place-specific projects in any context, the intervention and method approach discussed here could potentially be applied to other contexts.

From a local perspective, Mariestad municipality has a vast variety of material and knowledge assets that can positively contribute to a sustainable building industry future and counteract negative global trends." (Jonasson, Josefsson, & Marklund, 2019, p 12)

"In the face of threats, opportunities, and changes, Mariestad must find a way to not only survive but become a resilient, thriving city and municipality in the long term. Mariestad holds a great potential as a national pioneer of sustainability and self-sufficiency in that it is home to a vast amount of local resources in a variety of forms, including food, material, biodiversity, and special knowledge derived from the existing local conditions. Creating a strong network for sharing knowledge and promoting diversity provides resilience towards future change." (Jonasson, Josefsson, & Marklund, 2019, p 8)

"By understanding the qualities that make up Mariestad's identity and mapping available materials, it is possible to identify that which can be used in both traditional and innovative ways, resulting in a proposed circular economy-focused building project." (Jonasson, Josefsson, & Marklund, 2019, p 12)

Extensive site research and analysis of Mariestad municipality was previously carried out by the author (Jonasson, Josefsson, & Marklund, 2019) and is that on which this work is based. Not all of the previous work is shown in this thesis.

Figure 22: Skyline of Mariestad's historical city center September 2018

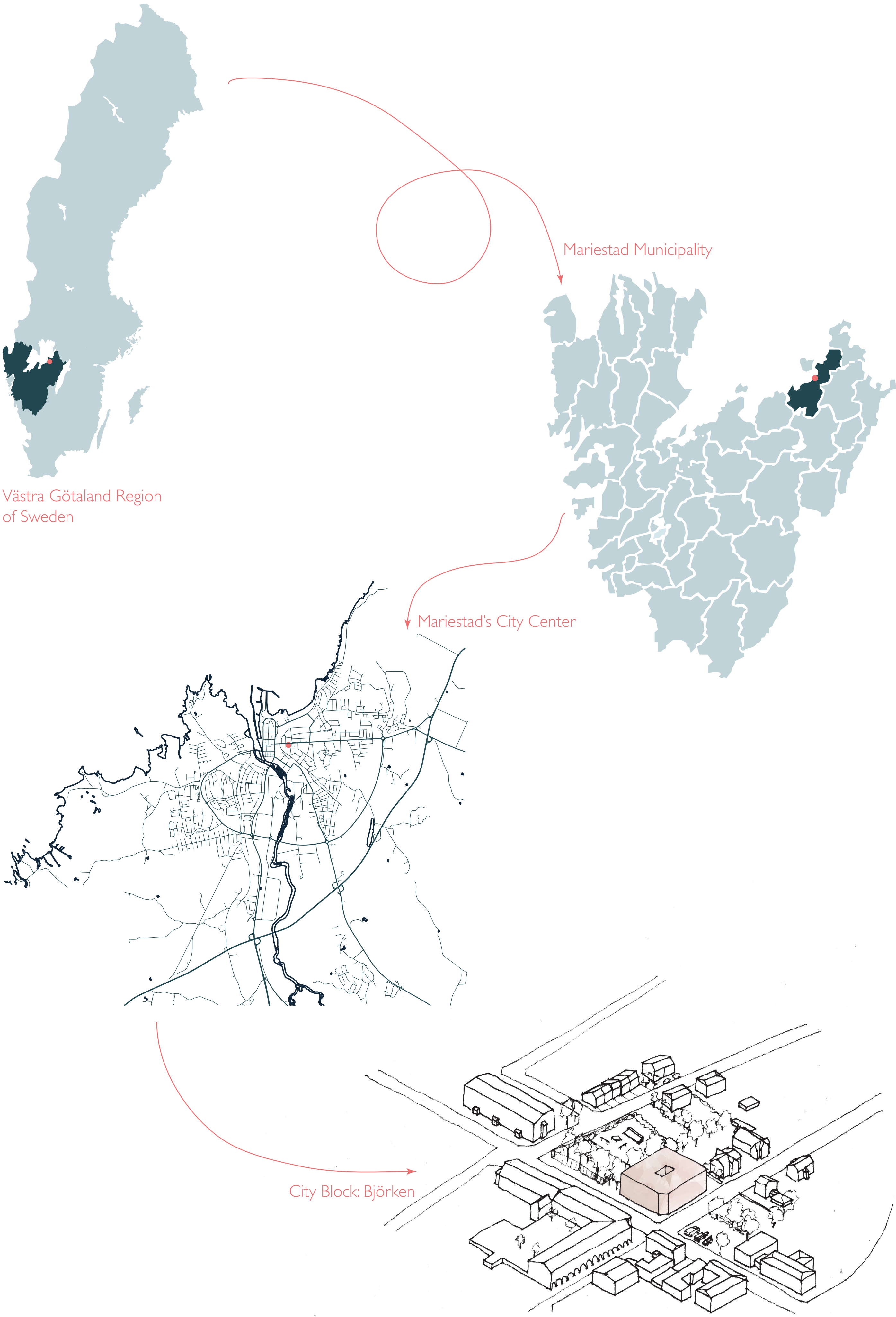


Figure 23: Contextual Site Zoom-In

DESIGN PROMPT

PROGRAM

OFFICE WITH GROUND FLOOR COMMERCIAL SPACES

The functions for which the site is zoned include: offices, retail, services, association spaces, and housing in the upper floors.

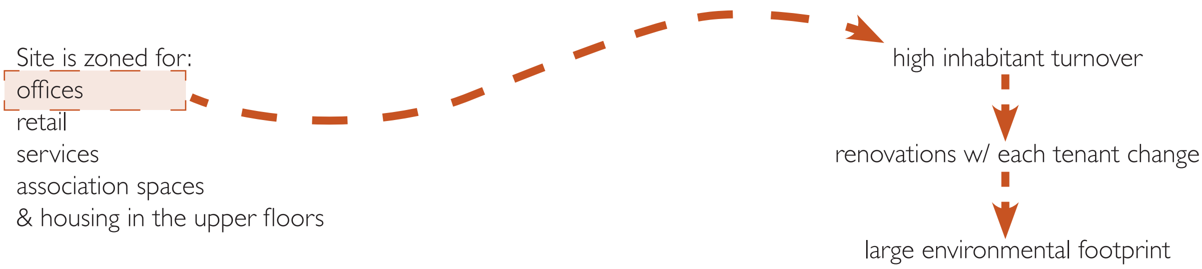
This proposal focuses on office design, as offices inherently require a transformative architecture due to high inhabitant turnover; each new group of users desires a space that meets their unique needs and reflects their identity, resulting in large quantities of waste and an increased environmental footprint with each tenant change. Such a program is an ideal opportunity for which to apply the circular design concept where there is a clear need for an alternative plan to handle the material transformation element.

The design must reflect future transformation and adaptation possibilities for the other programs for which the site is zoned, should the building's tenants or functions change in the future, as illustrated in Figure 25 to the right.

In accommodating the need for flexibility and adaptability, details and technical solutions must be designed with the expected lifetimes of the various building layers in mind.

Delimitation: future floor plan solutions for the other programmatic possibilities are not provided in this case study.

Additionally, a circular building should include an educational program component that trains the building owner, maintenance personnel, and occupants on how to install and care for the building and its materials so that the materials may be reused again in the future without losing value.



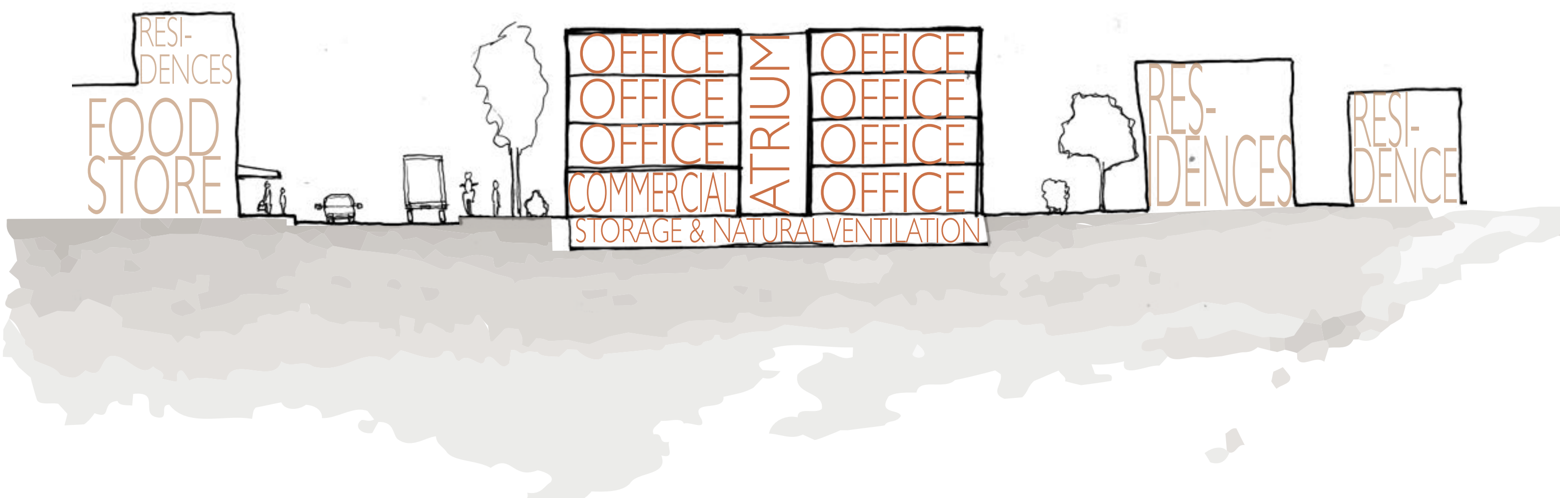


Figure 24: Programmatic Section

BUILDING OCCUPANTS

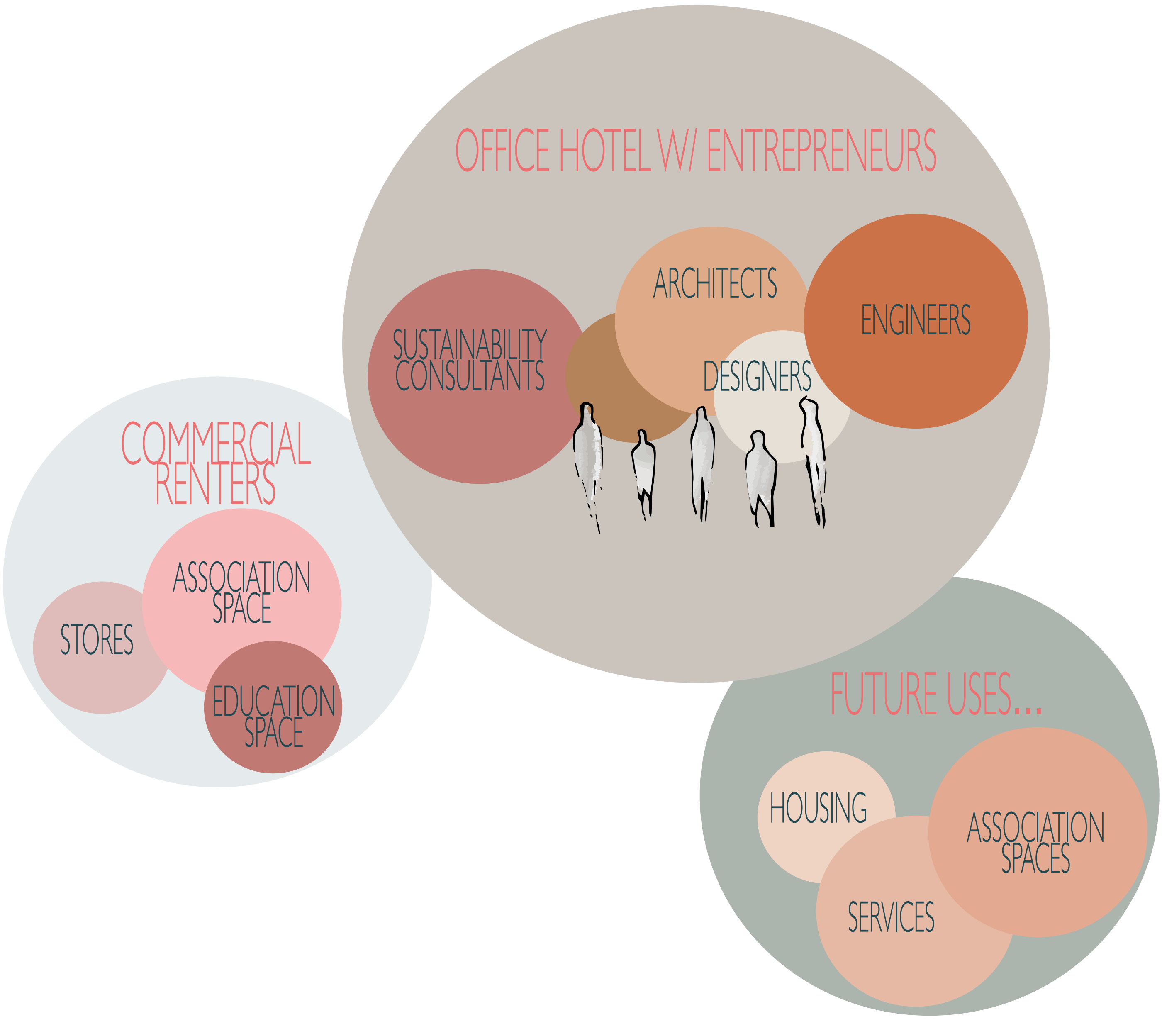
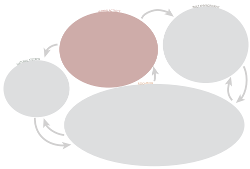


Figure 25: Building Occupant Diagram



DESIGNING REUSE

WORKFLOW
WHEN DESIGNING WITH & FOR REUSE

The diagram to the right (Figure 26) illustrates the non-linear manner in which the design process took place during the thesis investigation process.

A project design with and for reuse is unlike a typical design project. It requires a great deal of back and forth between the stages with constant refinement and adaptation, including later throughout the construction stage. Therefore, creating the workflow itself was part of the design process.

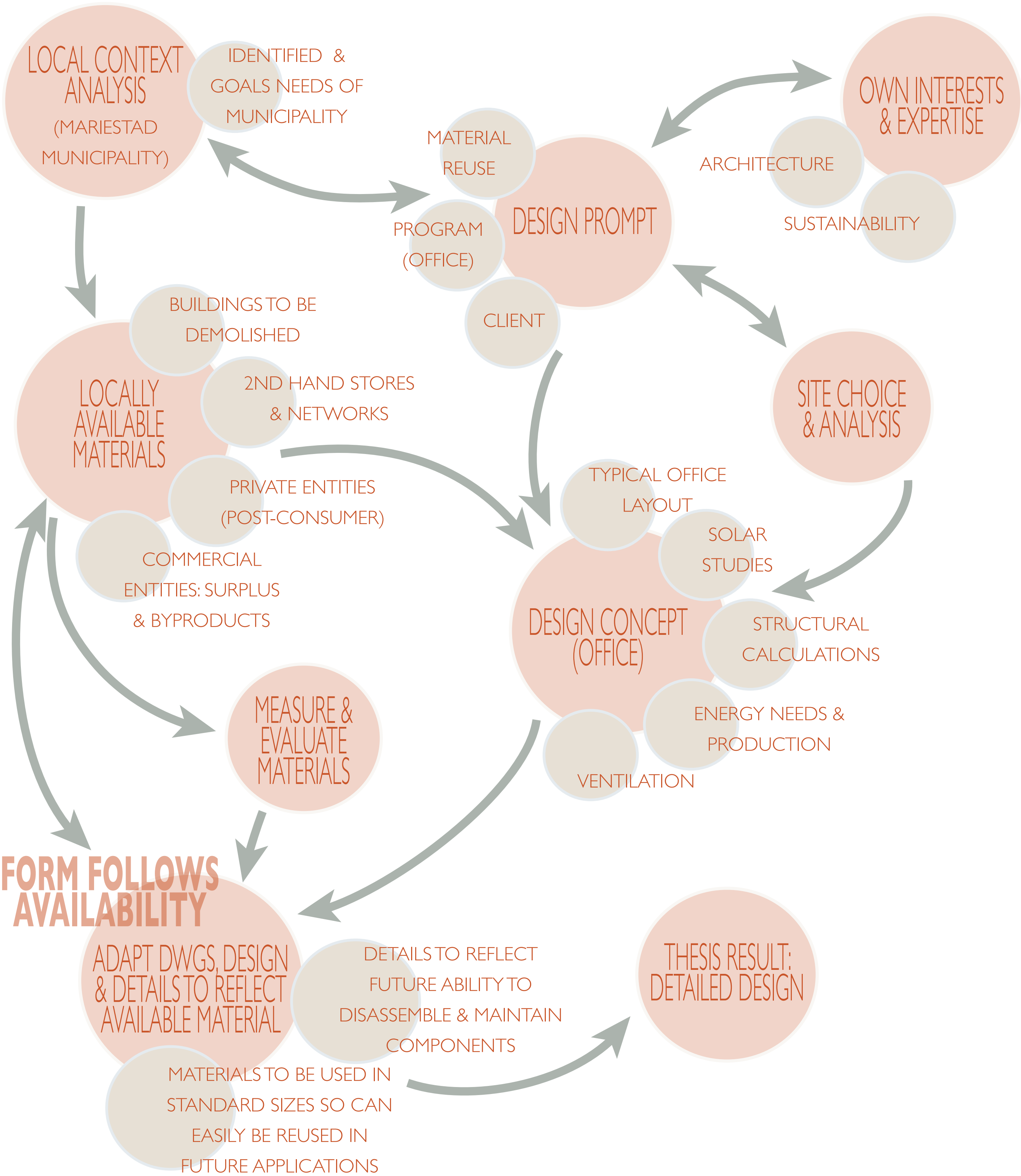


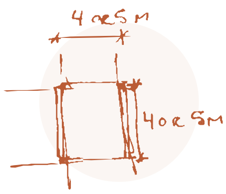
Figure 26: Reuse Workflow

DESIGN STRATEGIES

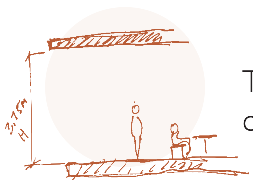
In order to meet the project aims and objectives, four main design strategies and a series of sub-strategies were established to guide and develop the final design concept proposal. These are illustrated below in Figure 27.

FUTURE TRANSFORMATION & ADAPTATION

Design in layers for maintenance & changing needs

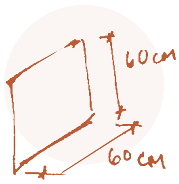


Simple structural grid

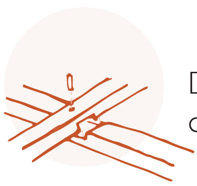


Tall floor to ceiling heights

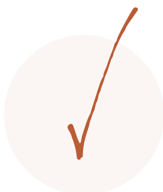
DESIGN WITH & FOR MATERIAL REUSE



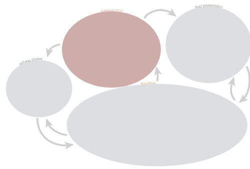
Design in standard dimensions



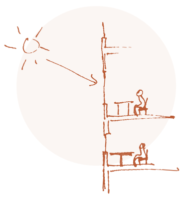
Detail for disassembly



Specify high quality materials



HEALTHY INTERIOR ENVIRONMENT



Daylight

Healthy materials (w/ little or no dangerous chemical content)

Ventilation

LOW ENVIRONMENTAL IMPACT

On-site energy production

Minimize building's embodied energy

Design for beauty

Figure 27: Design Strategies

SPECIFYING MATERIALS WITH LOCALLY AVAILABLE RESOURCES

INTRODUCTION

In specifying materials with minimal embodied energy, a sub-strategy of minimizing a building's environmental impact, sourcing materials locally reduces transportation energy and emissions and ultimately the total embodied energy of a material.

A large portion of the investigation included understanding the existing material stock and material availability in the Västra Götaland region. This included that which is available in existing buildings which could be used as material mines for future material reuse, as well as that which is currently available on the secondhand material market, both at brick and mortar stores and on online marketplaces.

When material mining within the existing building stock, the local building vernacular plays a critical role material selection and shaping the future buildings from reused materials. Buildings found in the countryside have a completely different makeup (in both detailing and material palette) from those found in the cities.

There are vast quantities of high quality material available both at secondhand material retailers and within the existing building stock, but there is no logistical structure to support its collection, cleaning, storage, and redistribution at this time, nor has reuse been shown to be less costly economically than the purchase of new material within the current system. During the 2019 Swedish Architecture Gala in Stockholm, Architect Maarten Gielen of Belgian firm Rotor Deconstruction described how it turned out to be more expensive to pack and transport CMU blocks without mortar from a temporary indoor installation that were given to his company for free than to purchase and deliver to site new CMU blocks from a typical building material distributor (personal communication, March 19, 2019). Because there is no economic incentive for building material reuse, it is up to the company or individual to implement material reuse according to their own motivation for environmentally friendly practices.

Based on the documented local materials, a catalogue of material found to be most readily available was created. The catalogue lists the quantity, possible applications for the material, and the ratings of value retention, the processing energy intensity required to transform the material for reuse, and its chemical content. The catalogue forms the basis for the design proposal.

CHOOSING THE BEST AVAILABLE OPTIONS

Material specification requires determining the best options. Both a preference hierarchy and a rating system were designed for this thesis to weigh the possibilities and guide the material selection.

While the material source types are listed in order of preference, the rating system components are all equally important.

HIERARCHY OF MATERIAL PREFERENCES SOURCES

1. Demolished buildings
(plan ahead for buildings slated for demolition)

2. Available at secondhand building material retailers

3. Products available on the market
(after recycling / processing)

+

RATING

→ Resource / waste management ranking (scale of 1-10)

→ Hazardous chemical content

→ Potential for future uses

→ Value retention

→ Energy intensity required for material processing / transformation for new or reuse

IDENTIFY BUILDINGS TO BE DEMOLISHED & RENOVATED MATERIALS MINING IN THE LOCAL BUILDING STOCK

GÖTEBORG

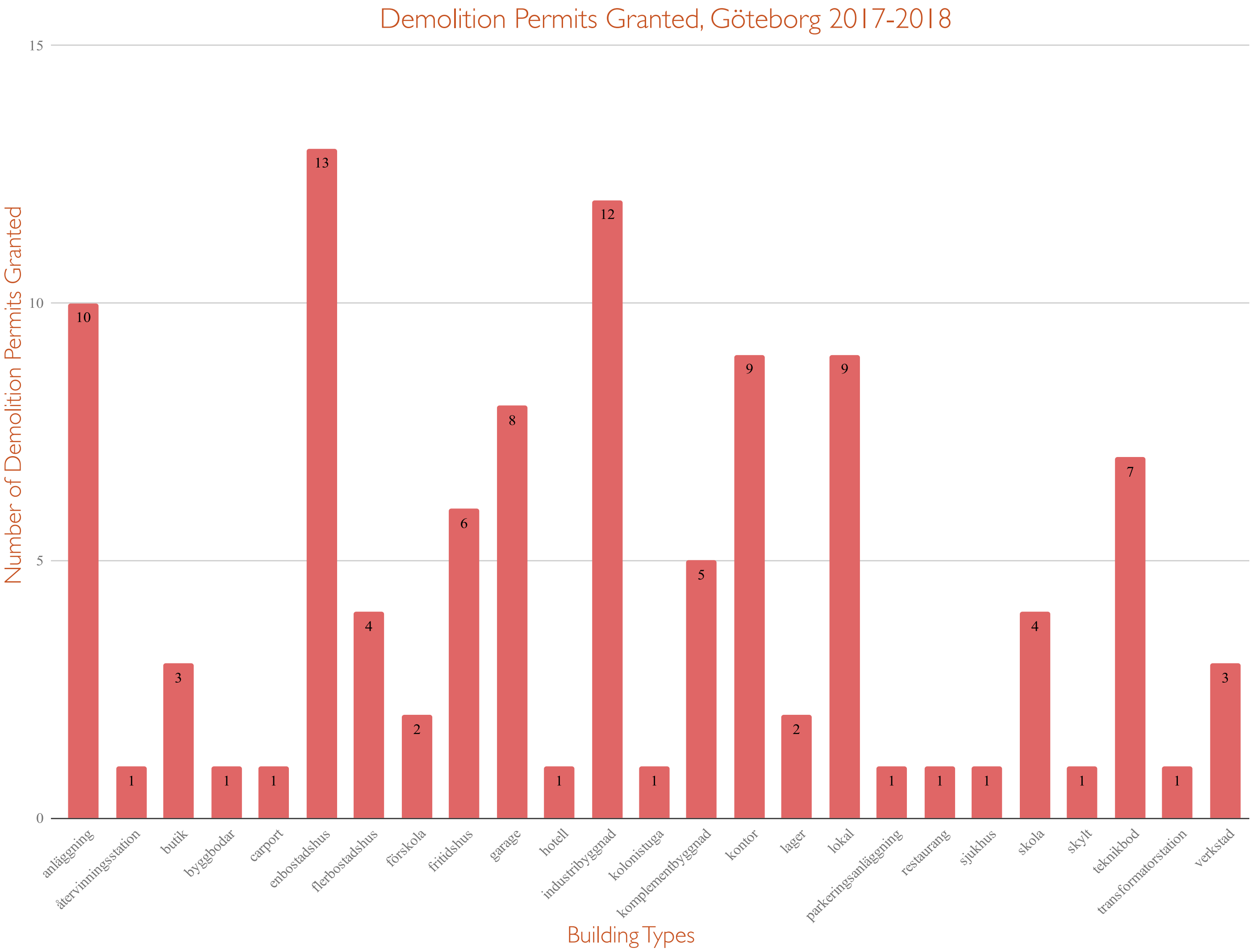


Figure 28: Chart created from 2017-2018 demolition permit approval in the city of Göteborg
Data courtesy of Göteborgs Stadsbyggnadskontor (M. Jacobssen, personal communication, February 15, 2019)

SUMMARY OF MATERIALS LISTED IN DEMOLITION PERMITS

Large quantities of structural steel and concrete were listed in the demolition permits. Materials were sorted and distributed to K&V, Ragnsell, Renova Miljö, RGS Nordic, & Stena Metall. A number of contaminated materials were noted, such as asbestos, CFC, electronic waste, lead, impregnated wood, PCB, & PVC.

acoustic panels
appliances
asphalt paper
brick
chipboard
concrete panels
concrete (reinforced & w/out)
copper
corrugated steel sheets
doors

electrical cables
eternit
flame retardant
flourescent lighting
freon
glass wool
glass fiberboard
glues
gypsum
impregnated wood

insulation
linoleum
loose wool insulation
mineral wool insulation
mixed metals
oil tanks
plastic moisture barrier
pipes (waste & fresh water)
roofing sheets
slag

structural steel
steel panels
structural wood
terracotta roof tiles
tile
ventilation ducts
windows

MARIESTAD

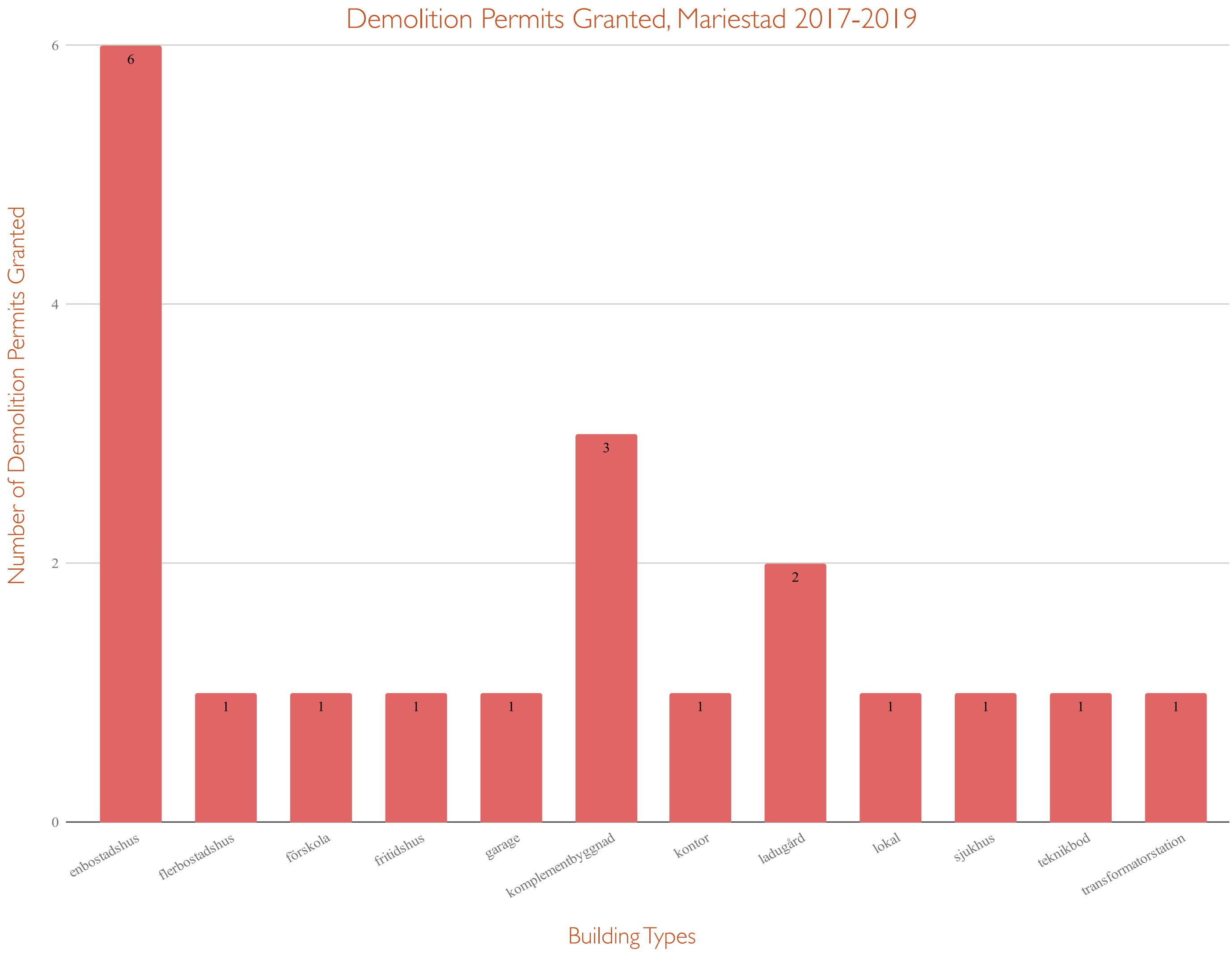


Figure 29: Chart created from 2017-2019 demolition permit approval in the municipality of Mariestad, Sweden Data courtesy of Mariestads Stadsbyggnadskontor (B. Friberg, personal communication, February 18, 2019)

SUMMARY OF MATERIALS LISTED IN DEMOLITION PERMITS

Structural wood was significantly more prevalent in Mariestad's waste removal plans filed as part of the demolition permits than those from Gothenburg. Some materials containing asbestos and quicksilver were noted. Most materials were planned to be sent to Bångahagens recycling center for handling (recycling, incineration, and other).

appliances
asbestos
brick (lime & cement mortar)
concrete (reinforced & w/out)
concrete blocks
concrete panels
corrugated steel sheets
doors
electrical cables
eternit roofing

flourescent lamps
gypsum
impregnated wood
insulation
loose wool insulation
MDF board
mixed metals
pipes (waste & fresh water)
plastic surfacing
porcelain

radiators
rockwool
roofing felt
structural wood
tiles
ventilation ducts
windows
wood carpentry
wooden panels

TRENDS IN THE AGRICULTURAL INDUSTRY PROVIDE OPPORTUNITY FOR MATERIAL SALVAGING

Figure 30: Barn in Bohuslän (October 2011)

Potential sources of used material are the iconic red-painted wooden barns that dot the rural Swedish landscape. The Västra Götaland region has a rich history of farming, both of crop and livestock production. More than half of the region's land use comprises agricultural land, with 16.2% used as arable land and 44.8% as productive forest (Regionfakta, 2019).

While the land use itself has not experienced drastic changes, developments in the agricultural industry have increasingly led to the loss of function and abondonment of the old, wooden structures, know as "överloppsbyggnader." Reasons include specialization, changes in technology and larger corporations taking over the industry. In their abondment, the buildings emblemmatic of Sweden's open landscape ultimately fall into disrepair (Länstyrelsen i Västra Götaland, 2002).

Without functionality or continued maintenance, the barns reach the end of their useful lives. To avoid the loss of the buildings' materials and preserve elements of the past, the structures can be carefully disassembled and their components reused in new applications.

In reusing salvaged material from local barns, one is at once making use of high quality material, maintaining its value, and preserving the history of the region.

CREATING A MATERIAL INVENTORY FROM BUILDINGS TO BE DEMOLISHED & RENOVATED

MATERIAL INVENTORIES OF EXISTING BUILDINGS INDICATE FUTURE MATERIALS AVAILABLE

In order to prevent materials from entering the waste stream and determine their best future applications, material inventories must be taken of existing buildings prior to demolition or disassembly. In doing so, the quantity and quality of buildings' materials may be established, and a cost- and time-efficient plan may be formed for the careful disassembly and proper sorting and management of the material. The material inventory should also determine the level of contamination of materials (should materials with dangerous content be present) and how and if these materials should be handled and separated from uncontaminated materials.

The first step is to create building material inventories (on an individual project scale), then show the information on a larger geographical scale, and finally determine what to do with these resources. It is necessary to identify the type and level of possible recycling and reuse on a large scale (C. Ehlert, personal communication, February 6, 2019).

See Appendix IV for extensive material inventories.

BARN A IN VARA, SWEDEN

Building Volume:	3583 m^3
Volume of wood in structure:	420m3
Ground Floor Area:	600 m^2
Roof Area:	780 m^2
Wall Area:	575 m^2
Year of construction & type:	Late 1800's
Renovated (roof):	Late 1900's

Materials: timber structure, bolts, wooden plank facade, wood doors, single pane glass windows, brick wall infill, stone foundation, stone floor pavers, poured concrete floor

Table 1: corresponding measured plans & material inventory shown in Appendix IV

Figure 31: Barn A

BARN B IN VARA, SWEDEN

Building Volume:	2634 m^3
Floor Area:	516 m^2
Roof Area:	580 m^2
Wall Area: 4	95 m^2
Year of construction & type:	Early 1900's
Renovated:	1987 & 2000's

Materials: timber structure, bolts, wooden plank facade, wood doors, single pane glass windows, CMU wall infill, stone foundation, poured concrete floor, plywood, corrugated steel panels, metal doors

Table 2: corresponding measured plans & material inventory shown in Appendix IV

Figure 32: Barn B

THE GREENHOUSE AT GÖTEBORG'S BOTANICAL GARDENS

Figure 33: the greenhouse at Göteborg Botanical Gardens (February 2019)

(Area accessible to public)

Building Volume:	5319 m^3
Floor Area:	1311 m^2
Roof Area:	1460 m^2
Wall Area:	953 m^2
Greenhouse exhibition floor area:	9100 m^2
Year of construction:	1981

Materials: Single pane glass, concrete foundation, steel structure, brick wall infill, terracotta tiling, piping for building services, glass & steel doors

Table 3: corresponding measured plans & material inventory shown in Appendix IV

According to Västfastigheter (the property owner), the greenhouse at Göteborg's Botanical Garden is slated for demolition in one or two years because it does not currently meet the garden's needs due to the poor insulating performance of the greenhouse's glass structure.

In moving towards more sustainable practices, Västfastigheter wants to find a way to keep the materials from the existing building from ending up in a landfill when making way for the new greenhouse structure. To avoid this, a material inventory will be taken by an appointed team of architects to determine which materials may be reused in the future and the amounts available.

The steps that the owner plans to take for the upcoming re-construction of the greenhouse follow their experience in 2018, when plans to salvage materials from a building at Sahlgrenska Hospital, also owned by Västfastigheter, were scrapped due to difficulties in planning, logistics, and cost. In the greenhouse project (and future Sahlgrenska construction), a team of professionals ranging from architects to secondhand material retailers has been assembled to create a strategy for inventorying, deconstructing, salvaging, and making available the materials.

*See Appendix I for a summary of the meeting with the team currently involved.

Not all areas of the building are accessible to the public. As a result, only rough approximations of the available material were possible.

SAHLGRENSKA UNIVERSITY HOSPITAL

Figure 34: Sahlgrenska University Hospital's main entry (May 2019)

Västfastigheter, the company that owns the Sahlgrenska Hospital buildings and Göteborg's Botanical Gardens, is planning major changes to the hospital campus' built environment. In addition to new construction in the immediate future, a large number of buildings, some of which date back to the late 1800s, require renovation or complete replacement in order to meet the hospital's modern needs. The scale of demolition and construction project will make a huge amount of material available, which, if properly evaluated, inventoried, and carefully unmounted, could be reused in any number of future construction projects, on the Sahlgrenska campus or elsewhere in Sweden.

A comprehensive inventory of the buildings to be renovated or completely replaced requires an extensive undertaking. Obvious materials that would become available in the deconstruction of campus buildings include large quantities of bricks and windows. In a visit to Building L, it was clear that the windows installed (type, size, & placement) did not fulfill thermal and daylight requirements. After removal, these windows can be rehabilitated and reinstalled in new projects.

SECONDHAND MATERIALS IN THE VÄSTRA GÖTALAND REGION

MATERIALS AVAILABLE FROM SECONDHAND RETAILERS


Fig. 35: Nails from Hus till Hus

Fig. 36: Pipes & Ducts from Hus till Hus


Fig. 37: Windows from Hus till Hus


Fig. 38: Windows, Doors & Lights from Hus till Hus


Fig. 39: Hardware from Hus till Hus


Fig. 40: Timber from Hus till Hus


Fig. 41: Marble, Slabs & Bricks from Hus till Hus


Fig. 42: Roof Tiles from Hus till Hus


Fig. 43: Plumbing Fixtures from Hus till Hus


Fig. 44: Bricks from Hus till Hus


Fig. 45: Spiral Stairs from Brattöns Återbruk


Fig. 46: Garage Door from Brattöns Återbruk

BRICK & MORTAR STORES FOR USED BUILDING MATERIAL SOURCING IN SOUTHERN SWEDEN & DENMARK

Fig. 47: Secondhand material online market map

ONLINE USED MATERIAL SOURCING PRE- & POST-CONSUMER, INDUSTRIAL BY-PRODUCTS

Sweden	
Blocket	blocket.se
Brattöns Återbruk	brattonsaterbruk.se
Bygg Igen	byggigen.se
Centrum för Cirkulär Byggande Marknadsplats	ccbuild.se/marknadsplats/
Kompanjonen	kompanjonen.se
Malmö Återbyggdepå	malmoabd.se
Denmark	
Genbyg	genbyg.dk
Netherlands, Belgium	
Harvest Map	oogstkaart.nl
Material District	materialdistrict.com
Rotor Deconstruction	rotordc.com/store/
France, Belgium	
Opalis	opalis.be/en/materials
Europe	
Pamono	pamono.se

MATERIAL SOURCING MAP

Material available for the case study can be sourced locally from a combination of secondhand building material retailers and buildings to be demolished (from within the 200km radius, as previously established in Part II).

Sources identified include the Göteborg Botanical Garden greenhouse, wooden barns from the site's rural surroundings, and secondhand material retailers in Västra Götaland (including Hus till Hus in Alingsås and Alelyckan at Göteborg's recycling center).

The diagram to the right (Figure 48) shows the origins of the identified materials. The secondhand retailers shown as located outside of the 200km boundary illustrate that there are other possible sources of material should the boundary be expanded or if one must search outside of the boundary to find a needed material or component that could be available elsewhere in Europe.

KEY

- Secondhand building material store
- Building to be demolished
- Quarry By-products
- Fixtures
- Windows
- Doors
- Car
- Train
- Truck
- Ship
- Bike cart
- Brick
- Terracotta Roof Tiles
- Corrugated Metal Panels
- Wood Planks
- Timber
- Steel

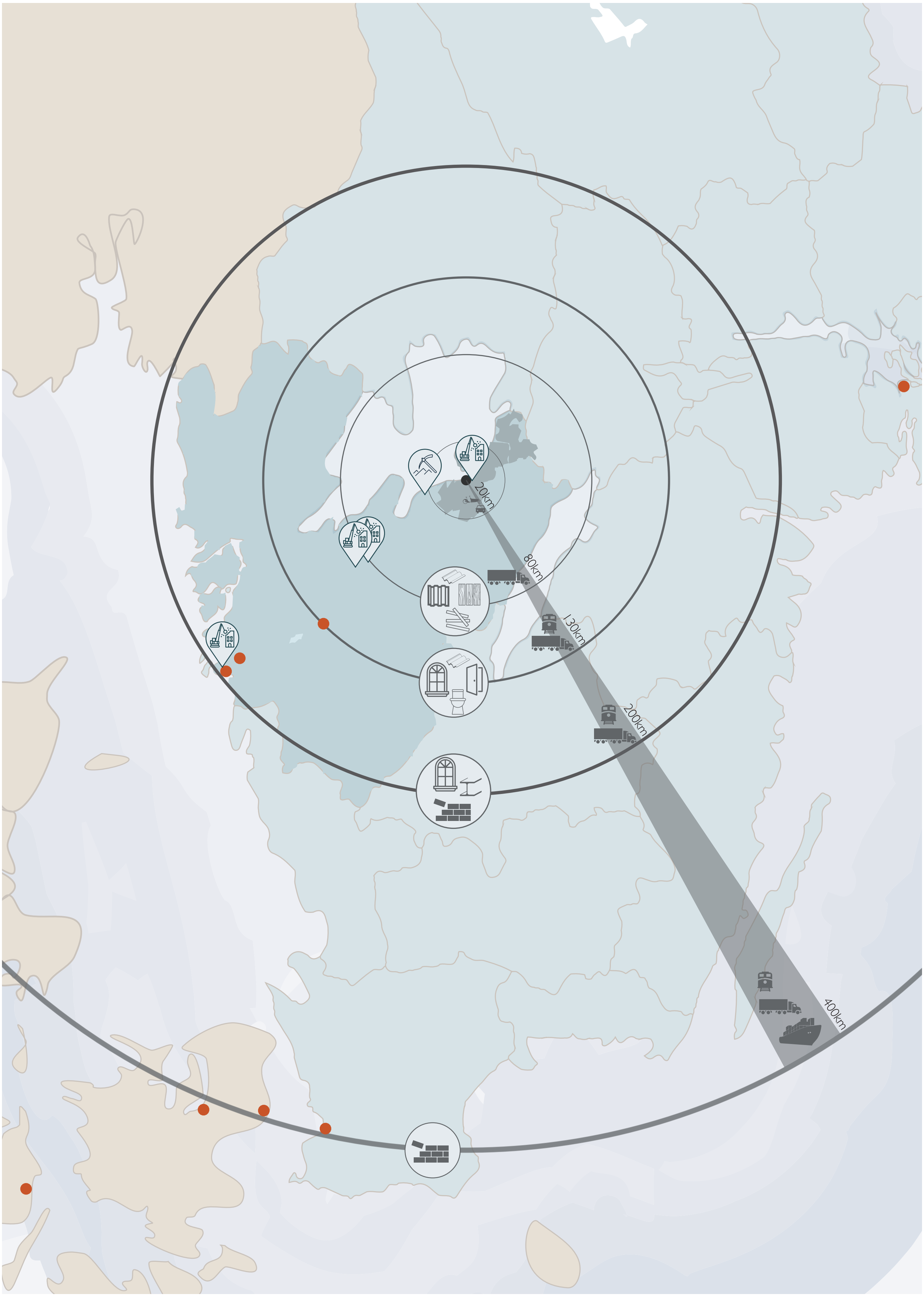
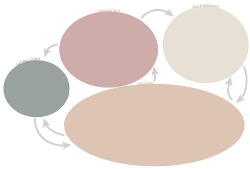


Figure 48: Map of current conditions for secondhand building materials sourcing in southern Sweden



EVALUATING AVAILABLE MATERIALS & THEIR POTENTIALS

DESIGN OF THE RATING SYSTEM

The catalogue of chosen materials for the design proposal (Figure 49 to the right)is supported by a rating system, designed as part of the material inventory and sourcing method.

RATING: WASTE MANAGEMENT HIERARCHY

The rating of the material reuse, recycling, or disposal (***1-10***, with 1 as the best and 10 as the worst) is based on the hierarchy established by the *Delft Ladder* waste management strategy referenced in Part II.

ENERGY INTENSITY REQUIRED FOR MATERIAL PROCESSING / TRANSFORMATION FOR NEW OR RE- USE

The classification of energy intensity has been determined by the author based on the material hierarchy established in Part II and the degree of energy usage required in material processing. The lower the energy required for processing or transformation, the better (and the lower the product's embodied energy).

LOW: component or material reuse in a form nearly identical or similar to its original state, requiring minimal work to adapt to the new installation or assembly (i.e. cutting, connecting, cleaning, transport)

MEDIUM: a material or component requiring some processing energy to make it available for a useful new application or assembly (i.e. cleaning, connecting or adhering, cutting, heating, etc.)

HIGH: a material that must undergo an energy-intensive recycling or transformation process to make it available for new use, function, or assembly (i.e. heating, grinding, shredding, adhering, etc.)

VERY HIGH: a material that must undergo a highly energy-intensive process to transform it into a new useful product (i.e. grinding, high heat, chemical processing, etc.)

FUTURE APPLICATIONS

Possible future uses are as proposed by the author. Future uses are here considered in terms of construction materials; however, there could be many additional uses in other applications or industries.

**"Original": the state in which the used building material or component was found or sourced prior to its reuse or transformation for the purposes of new construction.*

CLASSIFICATION OF VALUE RETENTION

The value retained by the building component or material in its reuse or transformation for useful new application has been determined by the author based on the original and ultimate functional, cultural, and aesthetic values. The degree to which the component or material maintains, loses, or gains in value is a question of societal perception.

GREAT LOSS: greatly reduces the value of the material, making future reuse or recycling nearly impossible (such as debris used for road fill).

LOSS: reduces possibilities for future reuse and is less culturally or aesthetically desirable, resulting in a loss of economic value (also known as downcycling). This includes the immobilization of a material with a useful new application, causing the material to be unextractable at a later time.

EQUAL: value is neither lost nor gained; this most likely occurs in the reuse of a material or component for the same purpose as originally intended.

INCREASED: By applying a new use to or transforming a component or material, perceived value is gained (also known as upcycling).

CHEMICAL CONTENT

Materials can contain chemicals that are harmful to the environment, workers, and contractors who must handle the material in construction or demolition, and building users, or any combination of the three. Emissions from hazardous material chemical content found in indoor environments can pose a health risk to inhabitants. Architects should prioritize the specification of materials with little or no known dangerous chemical content, including petroleum-based chemicals, formaldehyde, etc. Classification of risk is based on the Materialeatlas (Butera & Oberender, 2016).

FIGURE 49 & 50 KEY

Waste Management Rating	Best 1	← → 5	← →	Worst 10
Transformation Rating (Energy Intensity)	Low	Medium	High	Very High
Value Retention	Increased	Equal	Loss	Great Loss
Chemical Content	Low or 0	Some	High	Hazardous

MATERIAL CATALOGUE

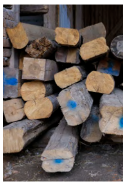
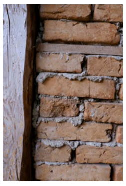
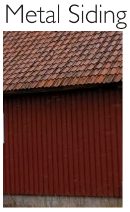
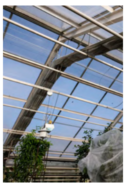
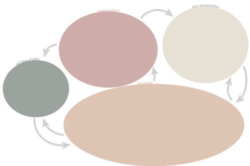
MATERIAL	QUANTITY	QUALITY	SOURCE TYPE	FUTURE APPLICATION	ORIGIN	RATING			
						WASTE MGMT RATING	PROCESSING ENERGY INTENSITY	VALUE RETENTION	CHEMICAL CONTENT
Wood 	+1530m .2m x .2m structure & many other wood components	Good	Barns: structure, facade	Structure, cladding, surfaces	Skaraborg	4			
Brick 	Large quantities (exact m^2 unknown)	Excellent	Barns, greenhouse, & Sahlgrenska: wall infill & facade	Wall infill, floor & ground paving	Västra Götaland Region	3			
Terracotta Roof Tiles 	+1360m^2	Good - Poor	Barns & greenhouse: roofing	Roofing, facade, foundation aggregate	Västra Götaland Region	3			
Corrugated Metal Siding 	+182m^2	Excellent	Barns: facade	Roofing & facade	Västra Götaland Region	3			
Glass 	+920m^2	Good	Greenhouse: facade	Fenestration	Göteborg	5			

Figure 49: Catalogue of chosen materials



ADDITIONAL SOURCES

EVALUATION OF PROCESSED MATERIALS FROM VARIOUS WASTE STREAMS ON THE MARKET

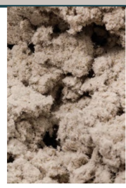
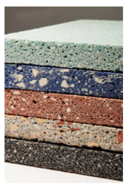
Original Material	Source Type	Waste Mgmt	Processing Energy Intensity	Value Retention	Chemical Content	Future Uses & Applications		Material Production Entity	Origin
Sewage, toilet paper, & diapers	Human waste water	5				Insulation		Recell by KNN Cellulose B.V.	Netherlands
Glass, bricks, concrete, porcelain, etc.	Construction & demolition waste	6				Interior & exterior bricks, tiles, & surface materials: cladding, interior detailing, furniture		WasteBased-Bricks by Stonecycling	Netherlands & other regional European factories
PP, HPD, LPDE, natural & synthetic fibers (rice hulls, nylon carpet)	Agricultural by-products & post-industrial polyolefins	6				Wood replacement in construction: outdoor use, architectural elements, flooring, interiors, work surfaces		Miura Board by Athyron LLC	Texas, USA
Earth from discarded bricks & construction waste	Construction & demolition waste	5				Commercial and residential interiors and exteriors, décor and furniture		Glazed Thin Brick by Fireclay Tile, Inc.	California, USA
High-performance polyurethane (PUR) and/or polyiso-cyanurate (PIR) insulation foam & panels	Construction & demolition waste	6				Rigid panel for construction and insulation materials such as profiles or edging strips, facades, bathroom, kitchen work surfaces, window, door, and furniture construction		Purenit by Puren gmbh	Germany
Glass & ceramics	Post-consumer, construction & demolition waste	6				Solid surfaces for interior & exterior walls, countertops and interior design		SilicaStone by ALUSID	United Kingdom

Figure 50: Catalogue of recycled materials on the market

REUSE DETAILS COLLECTED FROM REFERENCE PROJECTS

There are many examples of historical and contemporary reuse available. The photos here have been collected from study visits, literature studies, and reference projects.

While material reuse can be implemented in many ways, it is important to distinguish between the upcycling or downcycling of material. One must be critical of whether the application is the best use of the material and if it will allow for continued use and re-application in the future. Details that avoid the use of glue and allow for easy maintenance or disassembly are given priority.

Figure 51: Repurposed parquet & scrap wood as vertical surfacing material

Figure 51: Terracotta aggregate in the Roman Baths, Bath, UK build in 75 A.D. (April 2019)

Figure 52: 2 Roof tile facades at Lendager's Wasteland Exhibit vertically hung on clips & stacked with mortar (January 2019)

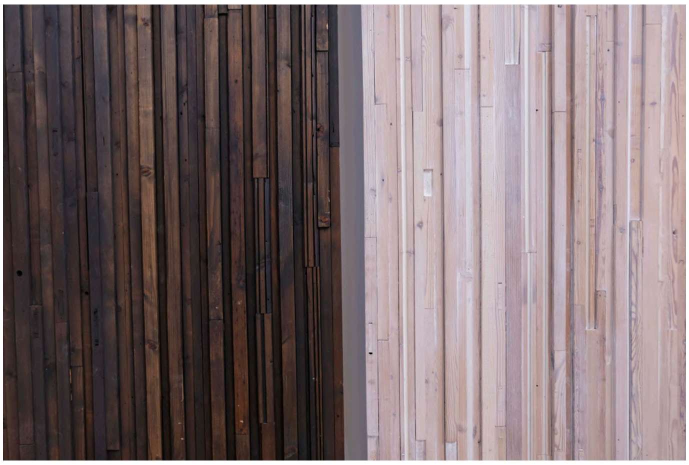


Figure 53: Acoustic wall paneling at Lendager's Wasteland Exhibit created from salvaged floors, doors, & window frames (January 2019)

Figure 54: New window assembly made from reused glass panes with new wooden frames at Lendager's Wasteland Exhibit at Vandalorum in Värnamo, Sweden (January 2019)

DESIGNING REUSE PROCESSES

SALVAGED TIMBER FOR STRUCTURAL RE-APPLICATION

Figure 55: Section through structural timber in barn

The Swedish landscape is littered with beautiful timber structure barns that are more and more frequently being abandoned and falling into disrepair due to changes in the agricultural industry. Big companies are both buying out smaller farmers for their land and pushing farmers out of the industry by undercutting their prices, making small-scale farming economically unfeasible. The timber from such barn structures is often older wood, comes in larger sizes, and is of better quality than that which is available today from large warehouse material suppliers. The high quality and wide availability of barn material makes it a perfect candidate for implementation in reuse applications.

One difficulty in working with salvaged timber is that it often contains nails, screws, and sometimes gravel, which can damage saw blades and planing machines (T. Johansson, personal communication, April 15, 2019). An additional step, which differs from typical raw wood processing, would require thorough cleaning and removal of debris from the salvaged timber.

Given that material processing of wood for building, especially structural applications, requires special machinery and a great deal of space, the process would be best suited to take place in a factory, which is already outfitted for such work, such as Moelven's in Töreboda, located only 18.4km from the building site.

As in the typical glulam production process, the structural testing and composition process should be documented and overseen by qualified experts both internally and externally to uphold safety and quality standards.

Figure 56 shows how the new glued solid timber structural elements might be taken and transformed from existing buildings and prepared for reuse.

WOOD AS THE PRIMARY MATERIAL

While steel has a high reuse potential and is readily abundant in the Swedish building stock, it requires off-site processing, high energy consumption in transformation, and heavy machinery. Wood is also widely available and is more easily transformed on site using less energy. There are also strong Swedish traditions of wood craftsmanship, particularly in Mariestad, which is home to Dacapo, a university dedicated to cultural building craftsmanship studies.

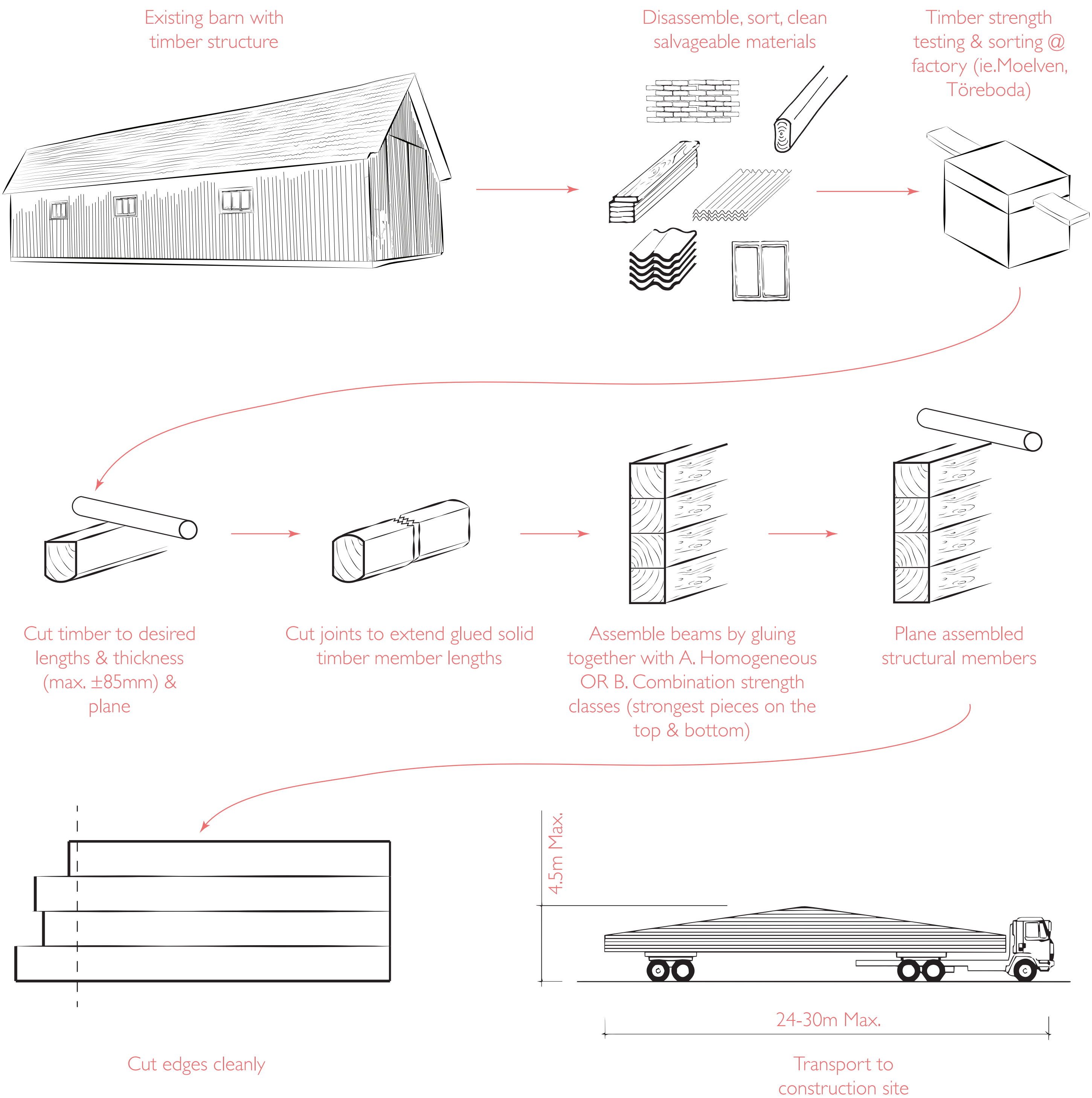


Figure 56: Salvaged timber re-processing for new application as glued solid timber

While glass has high potential for recycling, disassembling windows only to incinerate the wood for energy recovery and melt the glass to create new requires a great deal of processing energy. According to Lendager Group of Denmark, it takes about 60kg CO_2 to create one square meter window pane (2019).

It is possible to reuse the components to create new windows that meet energy efficiency standards without destroying the material. Lendager has established a method for processing salvaged windows, which involves installing salvaged glass panes in new wooden frames. They propose using the old wood frames for other interior products, such as wooden acoustic panels.

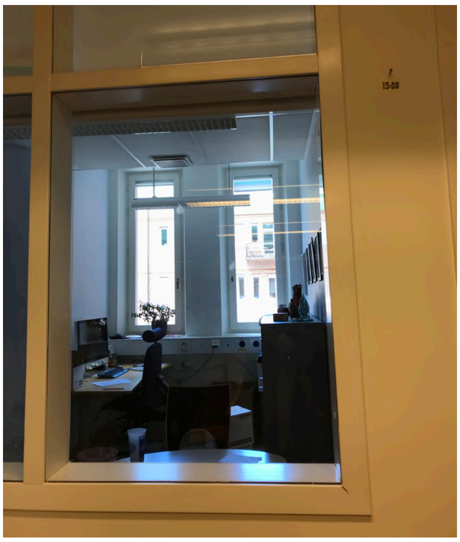
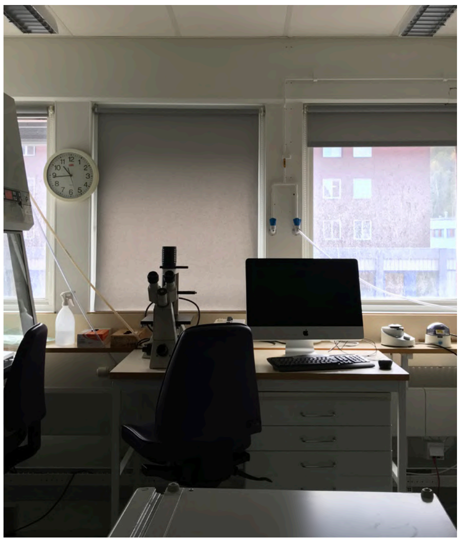
The processing diagram shown to the right illustrates a couple different variations for re-processing old windows as direct reuse and reworked assemblies.
There are vast amounts of salvaged windows available from both secondhand building material retailers, as well as buildings to be demolished in the local region. Re-processed windows may be mounted together to create a larger window component or stand-alone building components, as is typical.

The window rehabilitation options 4 & 5 shown in the diagram result in U-values of ±1.8 W/m^2,K and ±1.2 W/m^2,K depending on if the original reused window was single or double pane. No energy efficiency information was available for Lendager's method, shown in option 3.

It is important to consider that the window frames are a significant source of heat loss. In assembling a multiple reused frames, steps must be taken to maximize air tightness between the frames to reduce potential loss.

A rehabilitated window can reach a U-value of
1.2 W/m^2, K


Figures 57 - 58: Variety of windows sizes & types from local secondhand retailers Hus till Hus & Alelyckan (March 2019)

Figures 59 - 61: Interior & exterior Sahlgrenska Building L windows, many double glazed. Majority of exterior window dimensions: 0.9m x 1.05m (May 2019)

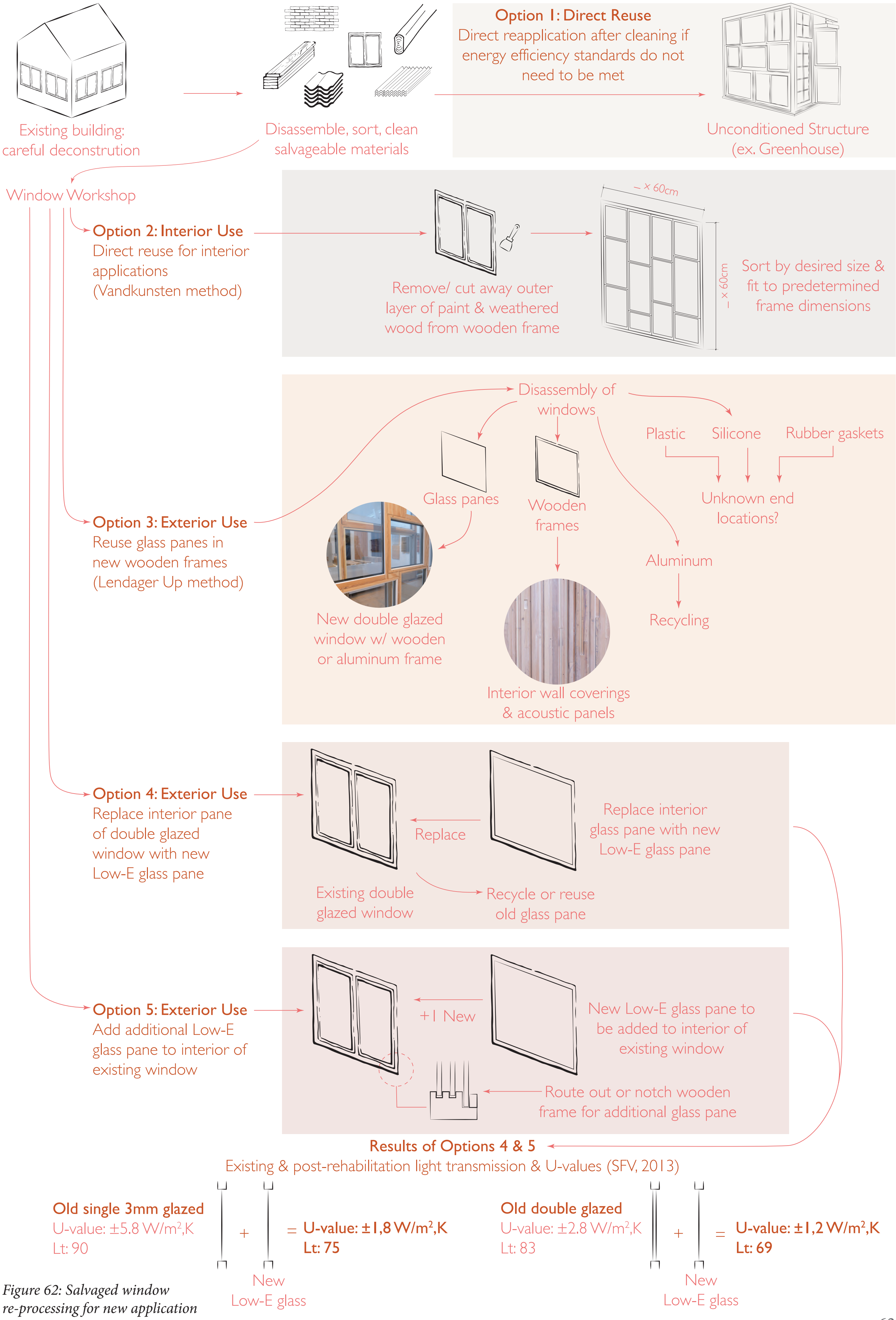


Figure 62: Salvaged window re-processing for new application

DESIGN DEVELOPMENT

CASE STUDY: SITE ANALYSIS

ANALYSIS: EXISTING CITY CORE CIRCULATION & LAND USE

KEY

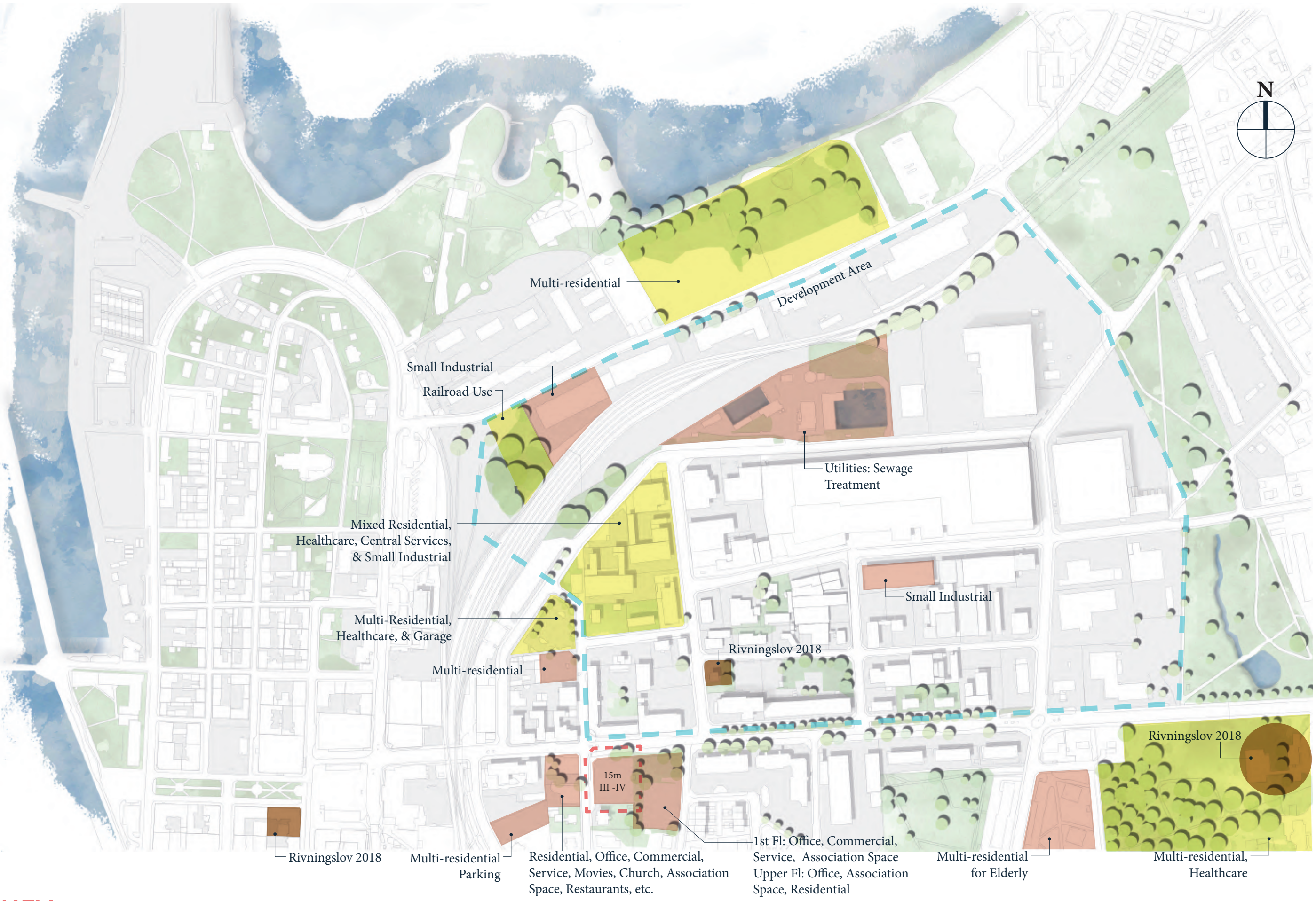
- Train Traffic
- Vehicular Traffic
- Pedestrian Traffic
- Industry
- Commercial & Service
- Bus Stop
- Site

Figure 63
Mariestad city center plan (not to scale)
Base plan by Arlid, Sjögren & Sjöberg Holtz (2019)

Figure 64: Google Maps streetview from site's northeast corner

Figure 65: Google Maps streetview from site's northwest corner

ANALYSIS: ZONING REGULATIONS & MUNICIPAL COMPREHENSIVE PLAN



KEY

- Development Area
- Site
- Demolition Permits 2017-2019
- Potential Housing Development
- Potential Public Sector Properties for Development

As suggested by the Comprehensive Plan & according to existing zoning regulations

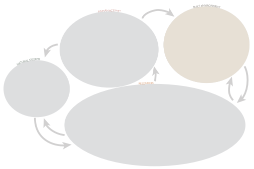
Figure 66
Mariestad city center plan (not to scale)
Base plan by Arlid, Sjögren & Sjöberg Holtz (2019)

The site was chosen based on the analysis of Mariestad's existing zoning regulations, the municipal comprehensive plan's proposed land use changes, and municipal detail plans.

The final site chosen is a brownfield site in the city center, used as a paved parking area serving nearby businesses. The current use of the plot does not maximize its potential.

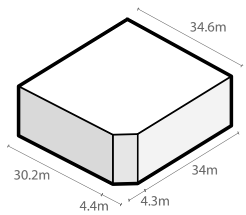
While the city block has mixed-use zoning, the property itself is zoned for offices, shops, services, association meeting spaces on the first floor, with offices, association meeting spaces, and housing on the upper floors. The maximum allowable buildable area of the site is based on zoning setbacks and height regulations.

A proposal on this site fits into the municipality's densification vision for the city center to make it more vibrant and attractive to new businesses and residents, as recent years have brought a reduction in the younger, working population and the movement of business and factories towards larger cities or less expensive locations. In providing additional office spaces, the city hopes to establish itself as a hub for business activity by offering an easily accessible location (centrally situated between Stockholm and Göteborg, Sweden's two largest cities).

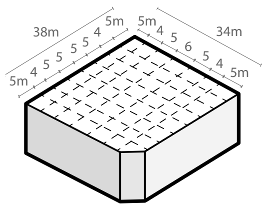


BUILDING VOLUMES

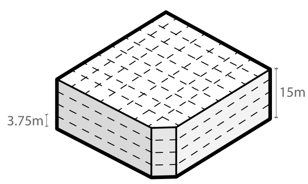
MASSING DEVELOPMENT



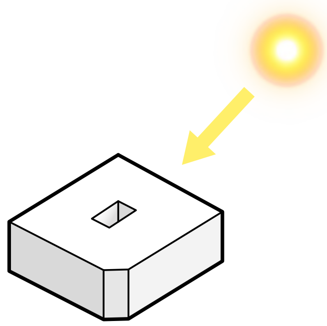
Maximum allowed building volume per zoning regulations



5m x 4m x 5m structural grid (glued solid timber)



3.75m Slab to slab heights
4 Floors as per zoning regulations



Atrium for interior daylight penetration
*See Appendix for sun studies

Figure 67: Massing development

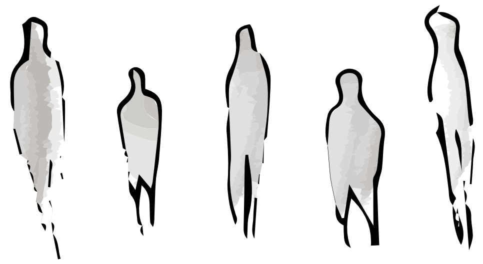
OFFICE LAYOUT

DESCRIPTION

The building structure is based on a 5m x 4m x 5m grid. This makes it possible for standard work area, toilet, and kitchen dimensions to fit, while providing ample circulation space and maximizing the floor area on the site.

The work surfaces are located along the windows to meet natural daylight requirements and provide the users with a good indoor environment.

Standard dimensions are from *Arkitektens Handbok* (Bodin, Hidemark, Stintzing, Nyström, 2019)



Floor Area / Employee:	12-15m^2
Occupiable Floor Area:	3717m^2
Maximum Employees:	309 people @ 12m^2 / Employee

Figure 68: Allowable occupancy of proposed office building

INTERIOR OFFICE DIMENSIONS

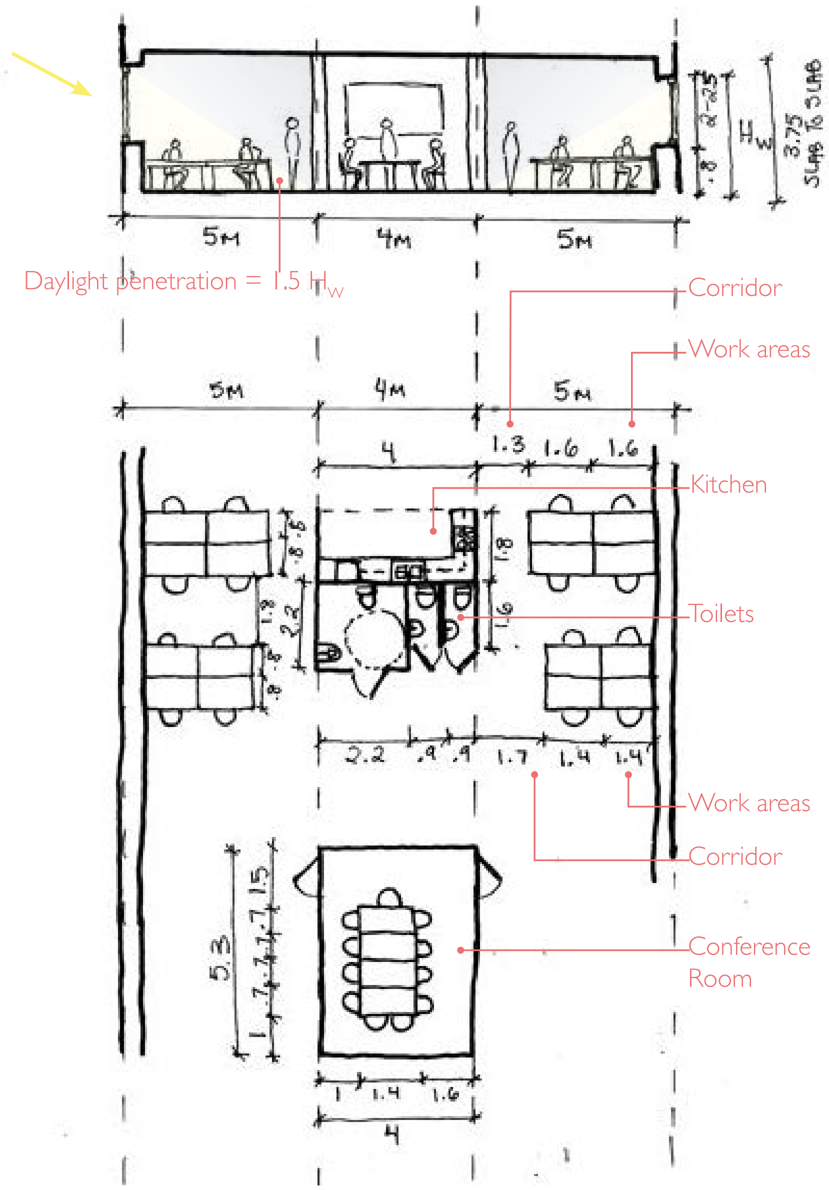
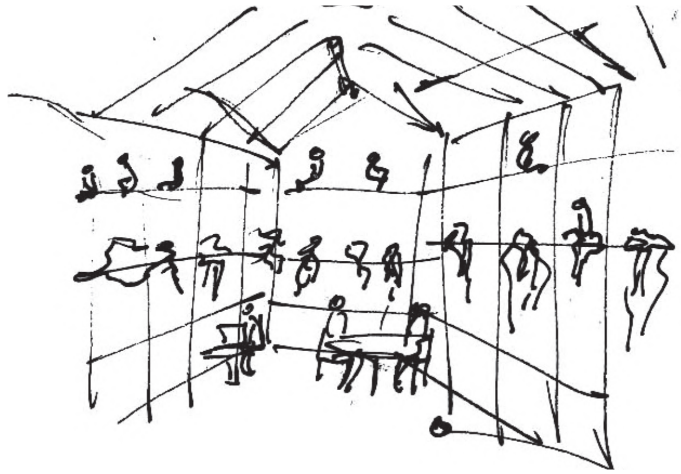


Figure 69: Interior office dimensions

CONCEPT SKETCHES

Exterior view approaching from the west along Stockholmsvägen

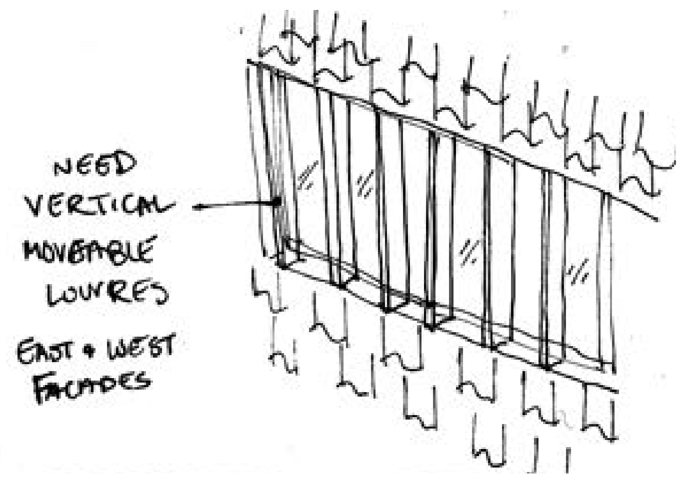
Figure 70



Interior: central atrium as a public work & social space

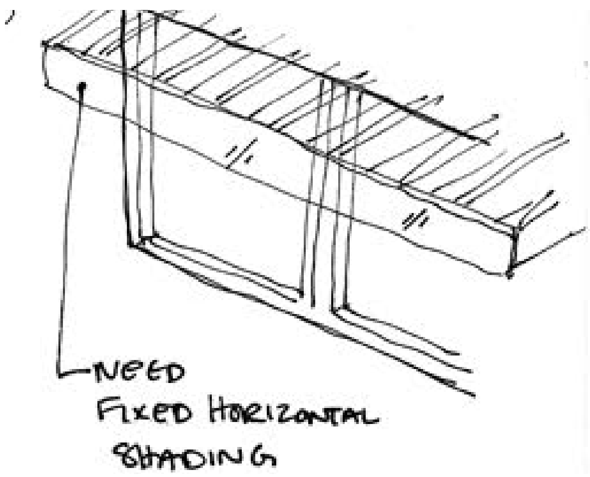
Figure 71

Shading devices needed to prevent overheating



West & East elevations: vertical louvers

Figure 72



South elevation: horizontal shading

Figure 73

ROOF DESIGN

While the design goal of providing flexibility for future building use changes as a method for designing a longer lasting and adaptable building would have been best served by designing a flat roof, the prioritization of maximizing material use and floor to ceiling heights resulted in an angled roof (15° tilt at an azimuth of 177°).

For a productive building surface, the angled roof option, calls for building integrated photovoltaic panels (BIPVs). The PV's must be a new product purchase to ensure maximum efficiency because PV production reduces as the panels age. By integrating the panels, it eradicates the need for additional roofing material, thereby reducing a building's embodied energy.

A flat roof would have allowed the user or building owner to have a choice between installing a green roof, occupiable roof space, and photovoltaic panels for solar energy production. To allow for the possibilities listed, the roof would have been required to carry the structural load called for in the most demanding instance (highest load), resulting in thick wooden beams that took away occupiable floor to ceiling space on the 4th floor.

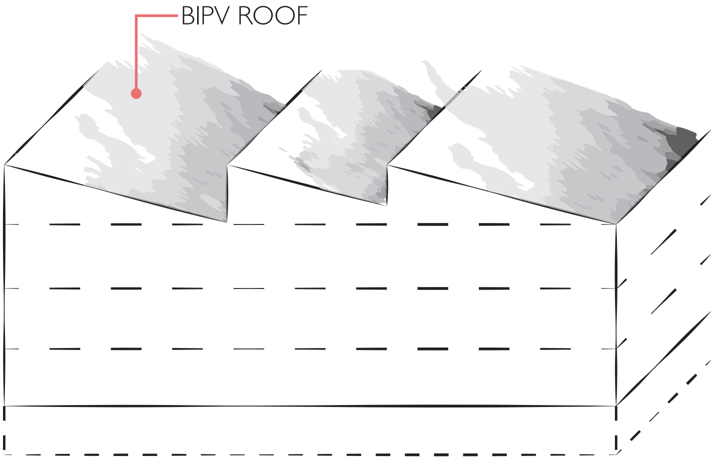


Figure 74

Fixed Building Integrated Photovoltaic Panels

Roof Area:	1310m^2
Module Type:	Premium
Production:	375 W per panel
Tilt:	15°
Azimuth:	177°
Number of Modules:	854
Total PV Production:	311,194 kWh/year

Table 4
**Energy production calculated with PV Watts Calculator*
pvwatts.nrel.gov/pvwatts.php

STRUCTURE

TIMBER

The main structure shall consist of salvaged timber from deconstructed barns sourced within the established (local) 200km radius. Connections and joinery shall be made with as few metal components as possible.

In order to uphold the open plan required for the office program and flexible plan layouts for future programs, the beams are required to span lengths of 4 and 5 meters.

The design loads to be borne by the timber structure in the new construction are significantly higher than those of the barns from which they originated, which only needed to carry snow loads of 2 kN/m² on a roof angle of ±33-41° (see Table 5 to the right).

The structural solution best suited to this application in size and strength is the use of glued solid timber elements from salvaged timber barns. As seen below in the curved structure of Malmö's Central Train Station, glulam and glued solid timber are able to span great lengths.

Per correspondence with Moelven's glulam factory in Töreboda (T. Johansson, personal communication, April 15, 2019), the largest possible wood planks that may be used in glulam are between 6-45mm thick, while the largest possible planks that may be used in glued solid timber are 45-85mm. The timber available from the barns ranges from ±100x100mm-200x250mm in size (see Figure 76 below), so Moelven recommends bolting the timber to assemble structural elements with enough strength to bear the higher design loads of the new building (live loads of 6kN/m² on the ground floor, 4.79kN/m² on the upper floors). However, this would result in structural frames too deep for this application, infringing on the occupiable floor to ceiling height. It was therefore determined that the best solution would be to cut the timber elements to thicknesses of ±85mm in order to optimize the existing material's strength and maximize material efficiency.

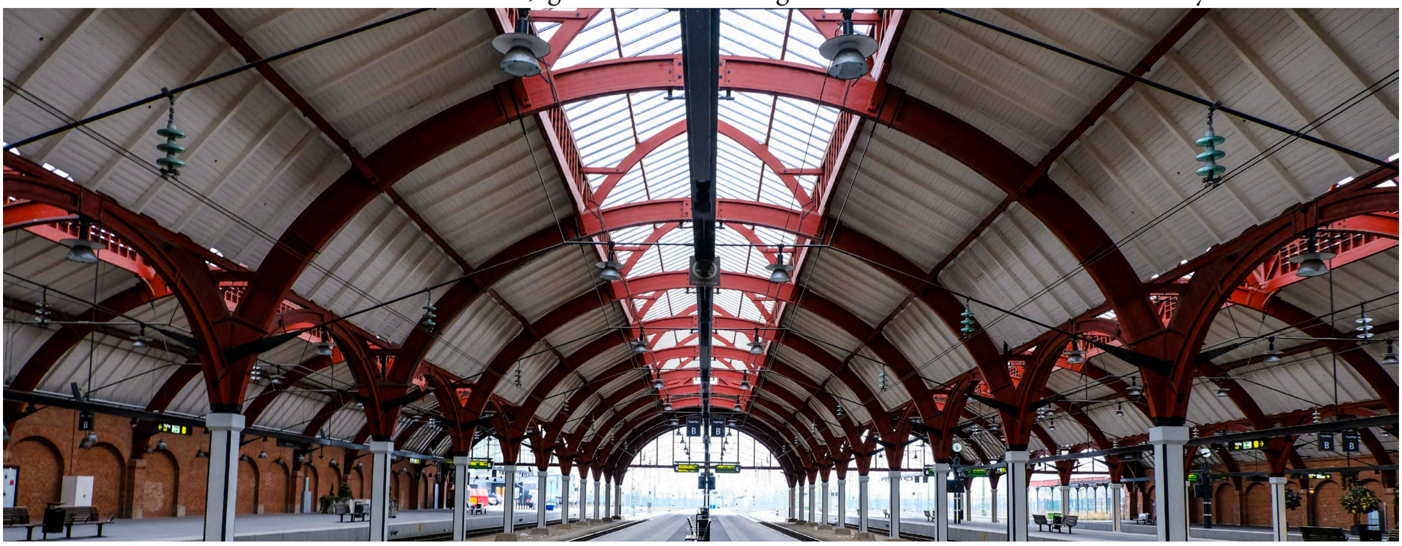


Figure 75: Malmö's Central Train Station (March 2019)

AVAILABLE STRUCTURAL TIMBER

Figure 76: Available used timber material (March 2019)

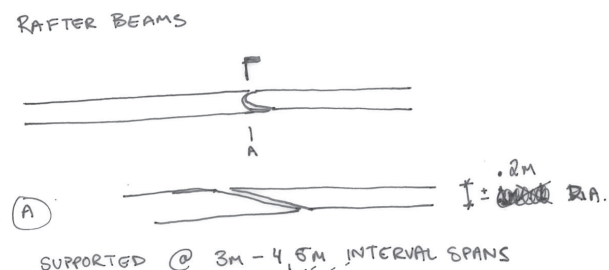


Figure 77: Sketched timber rafters from Barn A in Vara

Timber Cross Sections:
±.2m x .24m
±.1m x .1m

STRUCTURAL LOADS

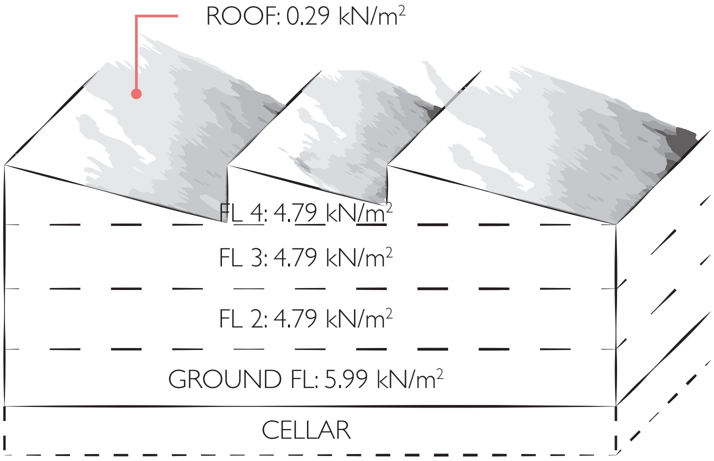


Figure 78 Design live loads

The structural load requirements of the building were determined using standard values for the various occupancies for which the lot is zoned. The design loads meet the highest load values for each of these occupancies on the respective zoned floors.

Live Loads

Possible Occupancies	Use	Min. Concentrated Live Loads (kN/m2)	kN/m2
Office	Lobby & 1st Floor Corridor	2.71	4.79
	Offices		2.39
	Office Partitions		0.96
	Miscellaneous		0.48
	Corridors >1st Fl		3.83
	Computer Rooms		4.79
Residential	Multi-Family & Corridors		1.92
	Public Rooms & Corridors		4.79
Stores	First Floor	1.36	4.79
	Wholesale		5.99
Assembly Areas	Fixed Seats		2.87
	Movable Seats		4.79
	Other		4.79
Manufacturing	Light	2.71	5.99
Roof	Roof garden / Intensive green roof		4.79
	Solar Panels		0.29

Design Live Load

	Heaviest Use (future possibilities)		kN/m2
1st Floor	Wholesale storage, light manufacturing, & all other occupancies listed above		5.99
Upper Floors	Public Rooms & Corridors		4.79
Roof	Roof garden / Intensive green roof		0.29

Snow Load

Item	kN/m2
Roof	2

Window Load

Item	m/s
Building	24

Table 5: All building occupancy live loads & design live loads

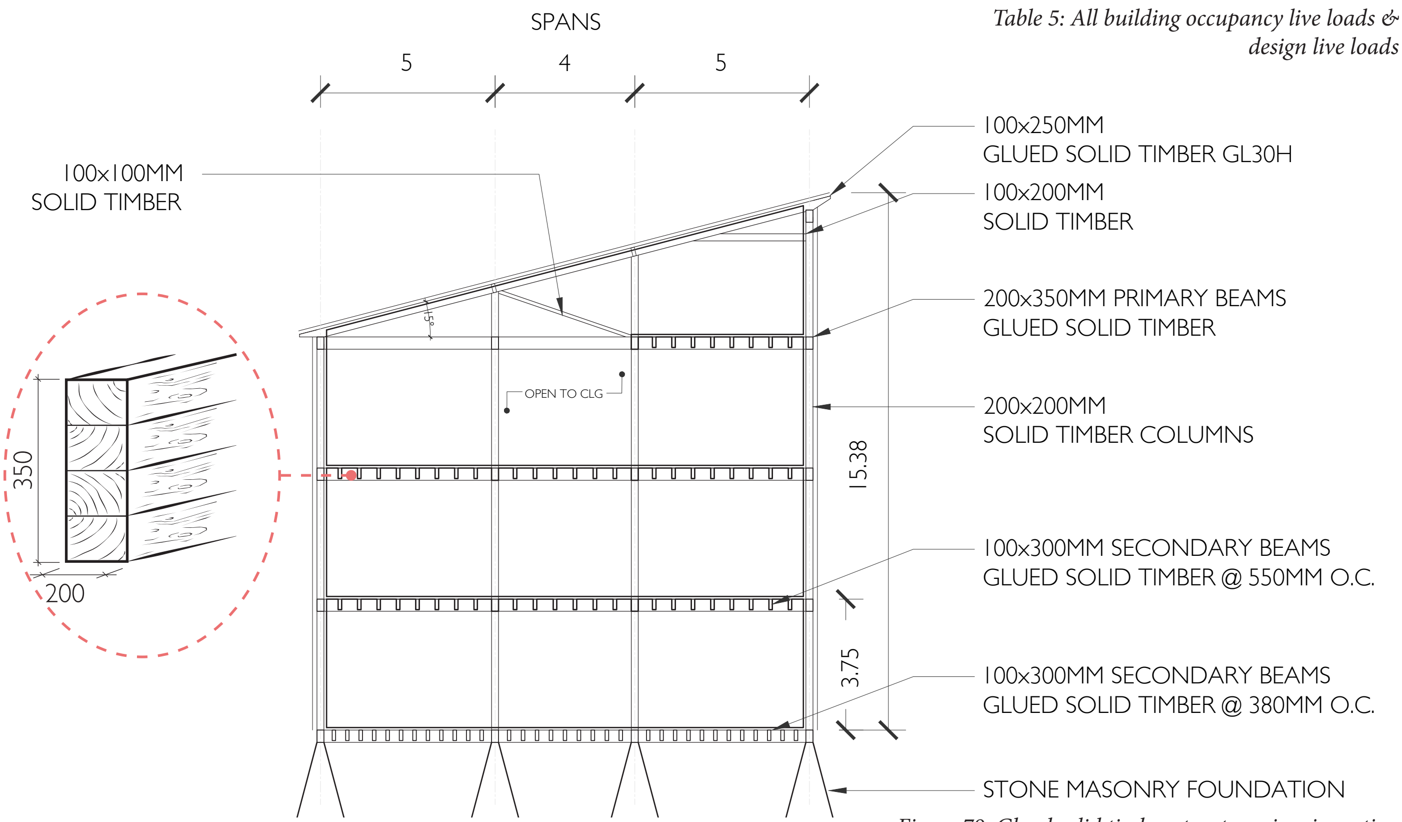


Figure 79: Glued solid timber structure sizes in section

MATERIAL EXPERIMENTATION

REUSED TIMBER & JOINERY

In experimenting with locally available material, focus was placed on the building structure, the backbone of the building (and that which holds the greatest embodied energy).

The old barns from which the new building's structural materials originate are joined together using typical Swedish handicraft techniques. Traditional timber joinery was practiced with minimal metal connections, if any, and instead relied on notching the wood to stabilize the various structural elements. Without nails and glue, both of which are difficult to remove and separate from other building layers, the structure can easily be disassembled and the components can be reused. This is an old example of design for reuse that can be applied in modern construction.

A prototype of the traditional wooden barn structure was built to better understand the joinery techniques so that they may be applied in the new structural design proposal.

The material used was 50mm diameter pine, previously fence posts near Barn A (p. 49) in Vara but was the same in growth origin and wood type as the barn's actual structural material.

The prototype material had previously been exposed to the outdoors, in contrast to the barn's structural material, which is protected by a roof and envelope. The material was similar in that both had a significant amount of dust and sand particles embedded in the wood grains. Future reuse applications would require extensive cleaning of the material.

The model production took place in Barn A and was required to be transported to Göteborg. It was therefore necessary to stabilize the frame using metal screws. In a real application, the screws can be substituted with wooden plugs or metal screws and bolts for more efficient disassembly and future reassembly.

Figure 80: Barn A Interior

Figure 81: Structural Joinery Detail


Figure 82: Sawing along the angle


Figure 83: Timber notching


Figure 84: End post notching

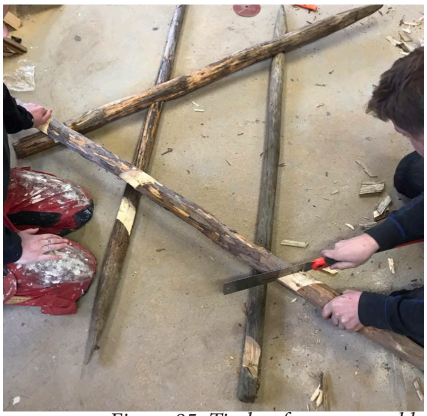


Figure 85: Timber frame assembly


Figure 86: Barn timber frame prototype
Scale ±1:10

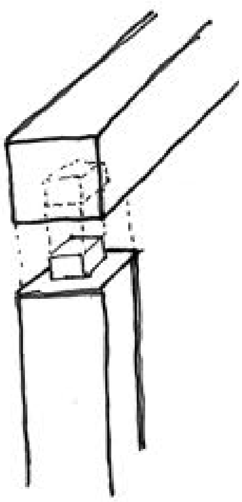
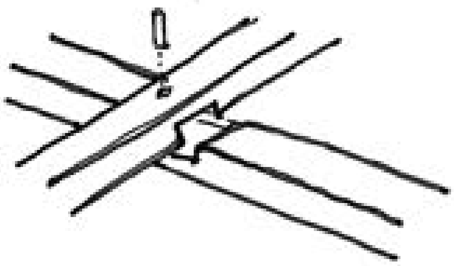



Figure 87: Joint sketches with column meeting beam (right) & wooden plug (left)

“I FOUND OUT THAT IF PEOPLE LOVE A BUILDING, EVEN IF IT IS MADE IN PAPER, IT BECOMES PERMANENT... MANY BUILDINGS MADE OF CONCRETE, IF THEY WERE MADE TO MAKE MONEY BY DEVELOPERS, THEY ARE VERY TEMPORARY.”

- Shigeru Ban

PART FOUR

Design Concept
Site Plan
Illustrated Perspectives
Program
Materials
Drawings:
Section -
Plans -
Elevations -

DESIGN CONCEPT

AN OFFICE BUILDING IN MARIESTAD CITY CENTER

The design concept presented here is one example solution where new construction consisting of reused materials and components may meet the immediate needs of a city, while also contributing to its long-term goal of promoting sustainability.

The office building proposal is an urban infill project that maximizes the use of the plot and brings job creation and life to the city center.

A well-designed, highly visible project can show the possibility of achieving beauty and the visualization of culture and history through material reuse. In its prominent central location, the building would reach all of the city's inhabitants in the hopes of garnering love and support for the continuation of the building material reuse practice.

Figure 88: Exterior Illustration
Looking east towards the building along Stockholmsvägen

SITE PLAN

DESCRIPTION

The building proposal site is located in Mariestad city center on an empty lot, which is slated for development in the near future.

The northern facade faces one of the busiest vehicular and pedestrian streets, Stockholmsvägen, while the east and south facades are adjacent to another empty lot and a residential villa area.

The roof plan is shown to in Figure 89 to the right, including the solar panel array and roof slope direction.

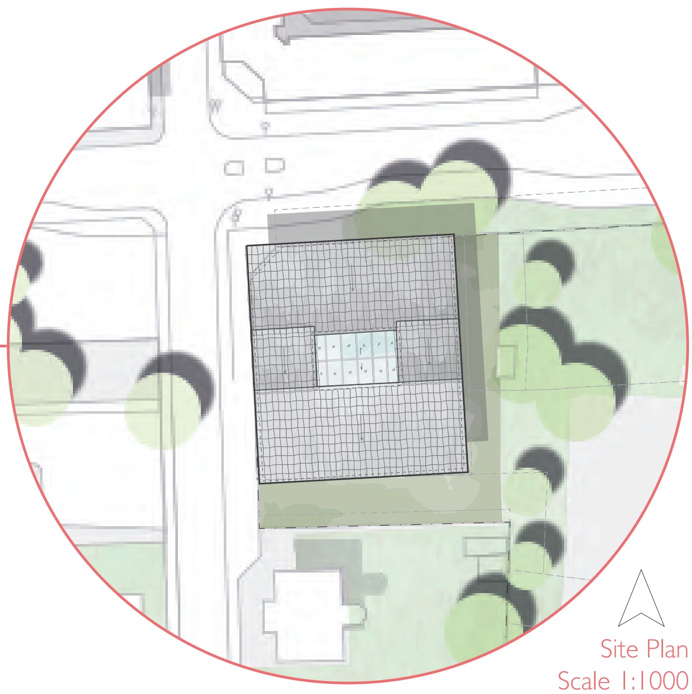


Figure 89: Proposed Site Plan

ILLUSTRATED PERSPECTIVES

Figure 90: Interior Office Illustration

The above collage illustration shows possible reused materials applied in the office interior. Wood in a variety of textures is the dominant feature in this collage, given that the majority of found windows, wood structure, and other building materials tend to be wood-based in the area.

Figure 91: Interior Atrium Illustration

Above is a view of the central atrium, where a window partition made of reused windows is featured. Brick, another abundant used material in the area, is used as ground paving. The upper interior walls are clad with typical red-painted Swedish wood from local wooden exterior cladding, while the exterior walls are clad in vertically hung salvaged terracotta roof tiles.

PROGRAM

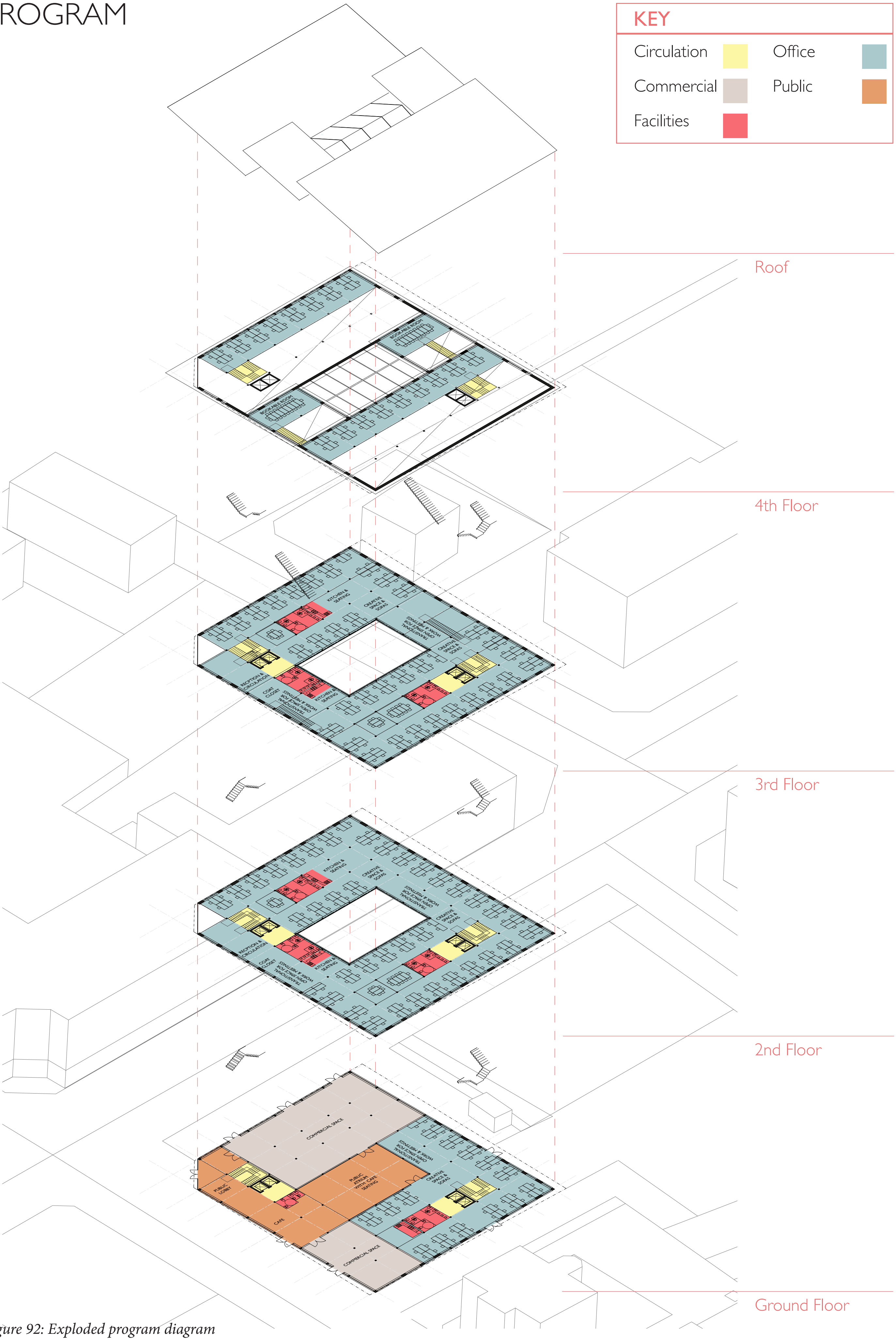


Figure 92: Exploded program diagram

DESCRIPTION

Select materials and their origins are proposed in Figure 93. All materials indicated are either widely available in abundant quantities or can be sourced from known upcoming demolition projects.

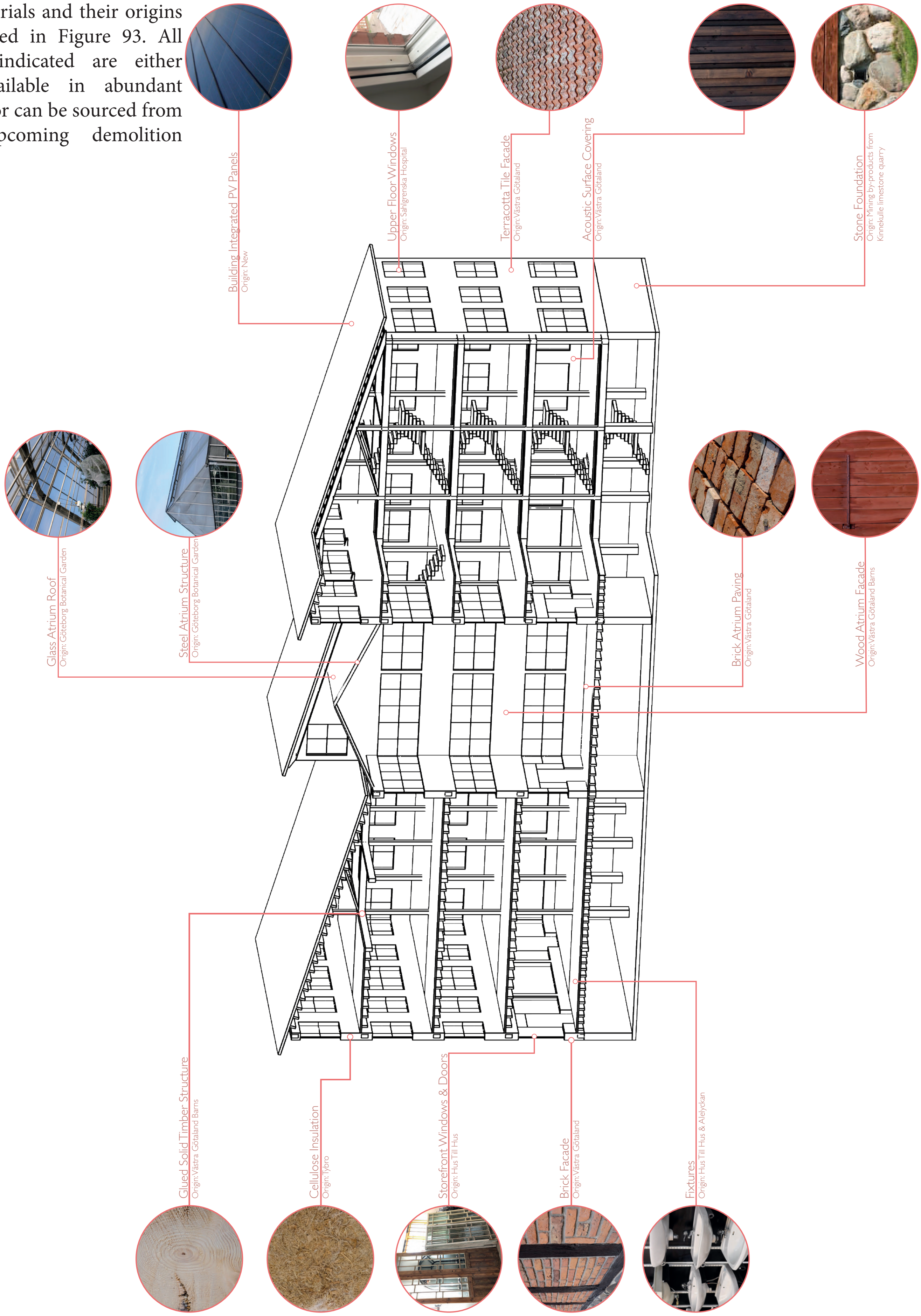


Figure 93: Section perspective with proposed materials & material origins

DRAWINGS

SECTION

The section below cuts through the building's north-south axis. It shows the central atrium, flanked by commercial spaces on the ground floor and office spaces on the upper floors.

The colored arrows diagrammatically indicate the building's hybrid ventilation system, using air pre-conditioning through the ground duct and at the cellar level, which is then drawn into the atrium with fans and expelled through the atrium ceiling's operable windows. Where the fourth floor levels are higher than the atrium, the air is mechanically drawn out directly to the exterior.

The atrium ceiling's operable windows are already built into the greenhouse roof sourced from the Göteborg Botanical Garden.

Bathrooms and individual rooms would require their own air intakes and exhausts.

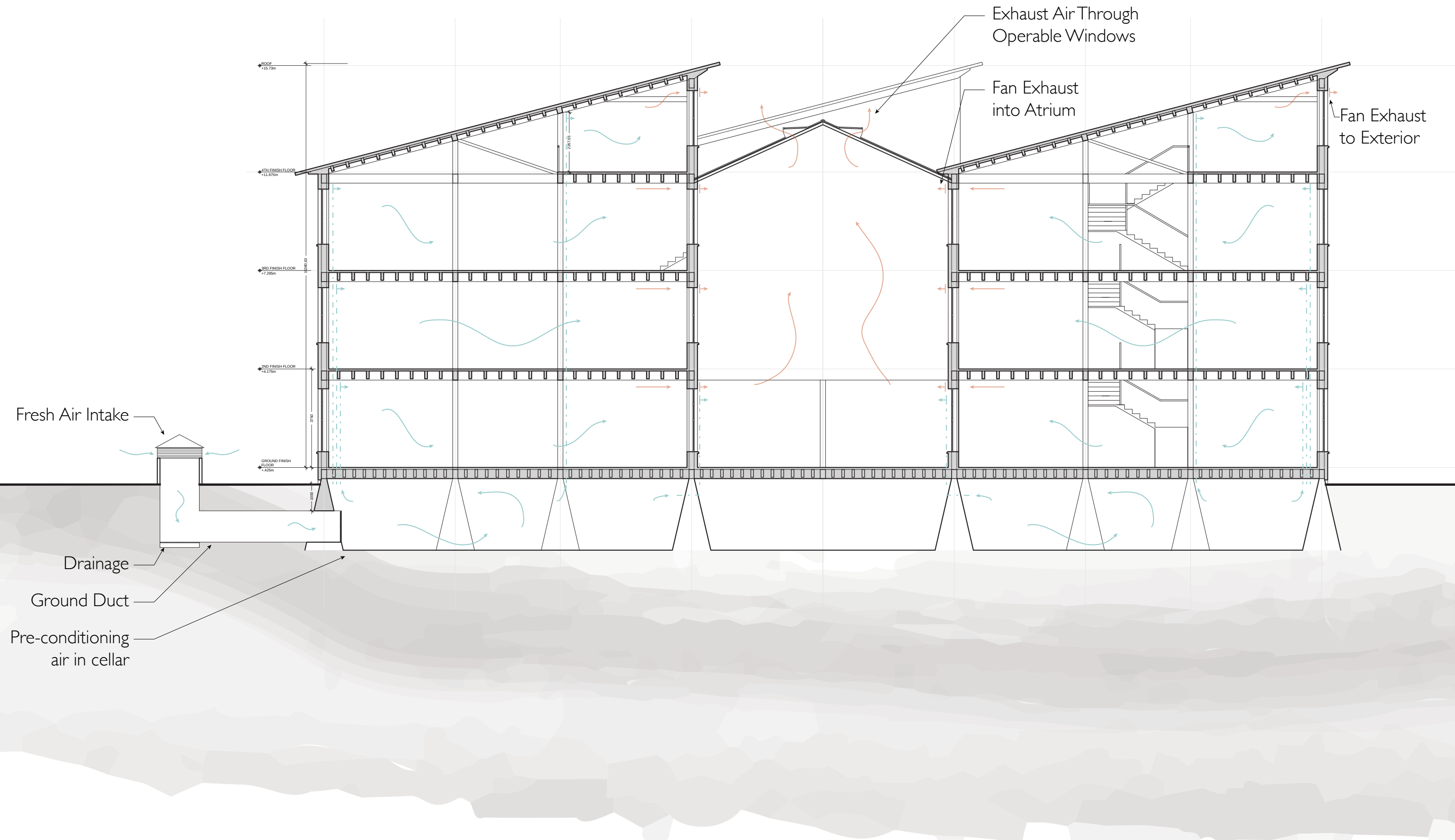


Figure 94: North-south section with natural ventilation

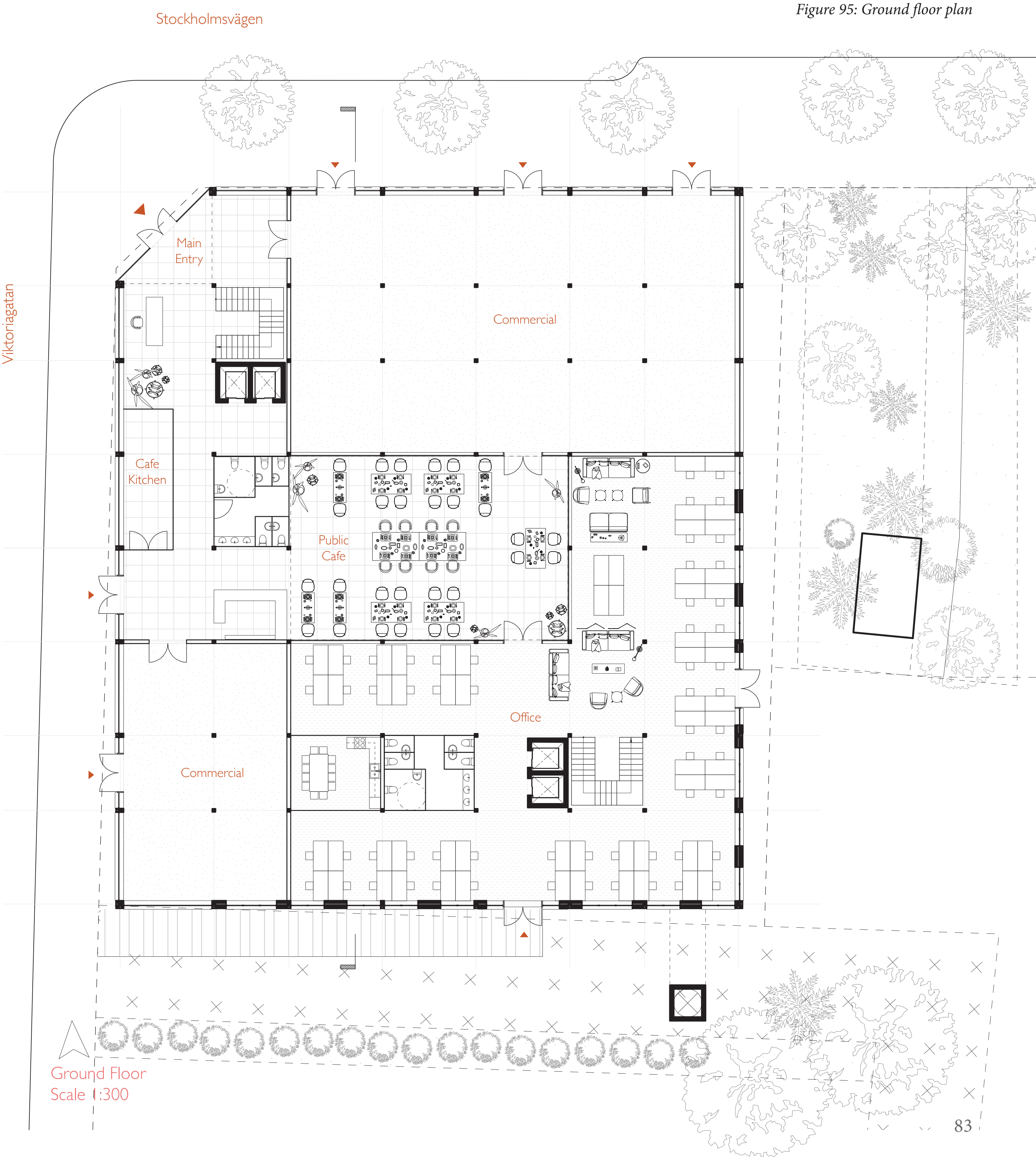
North-South Section
Scale 1:300

PLANS

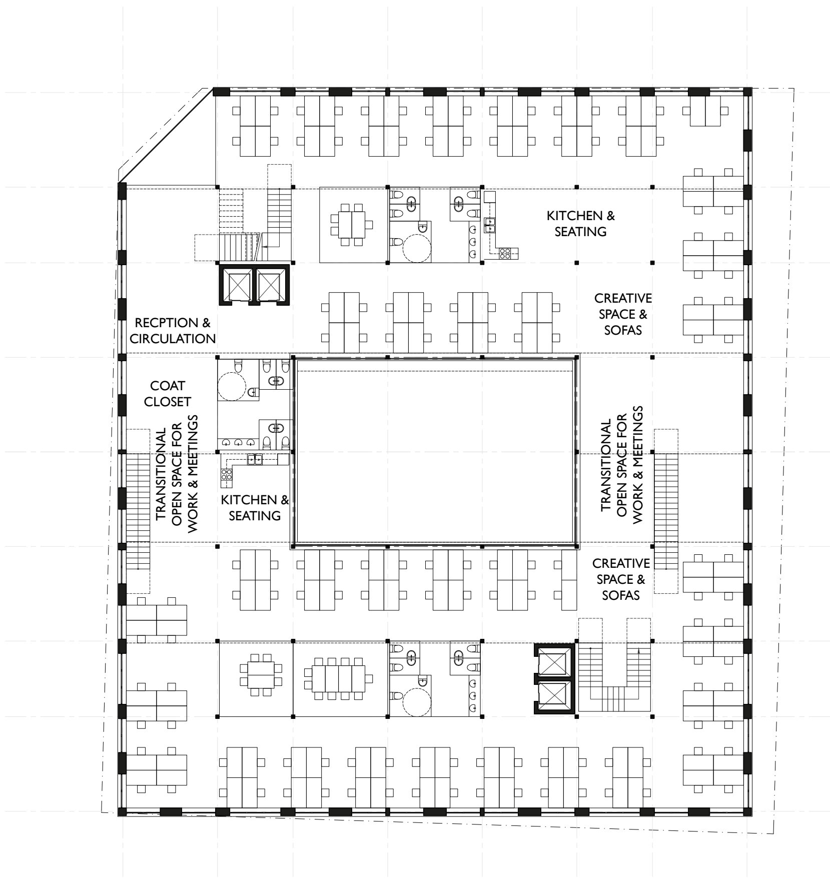
GROUND FLOOR

The ground floor opens up onto Stockholmsvägen and Viktoriagatan on the street-facing facades and faces an empty lot and a single family home area on the other two facades. A sample floor plan proposal is shown below where a main entry lobby, offices, a public cafe, and commercial spaces are currently situated.

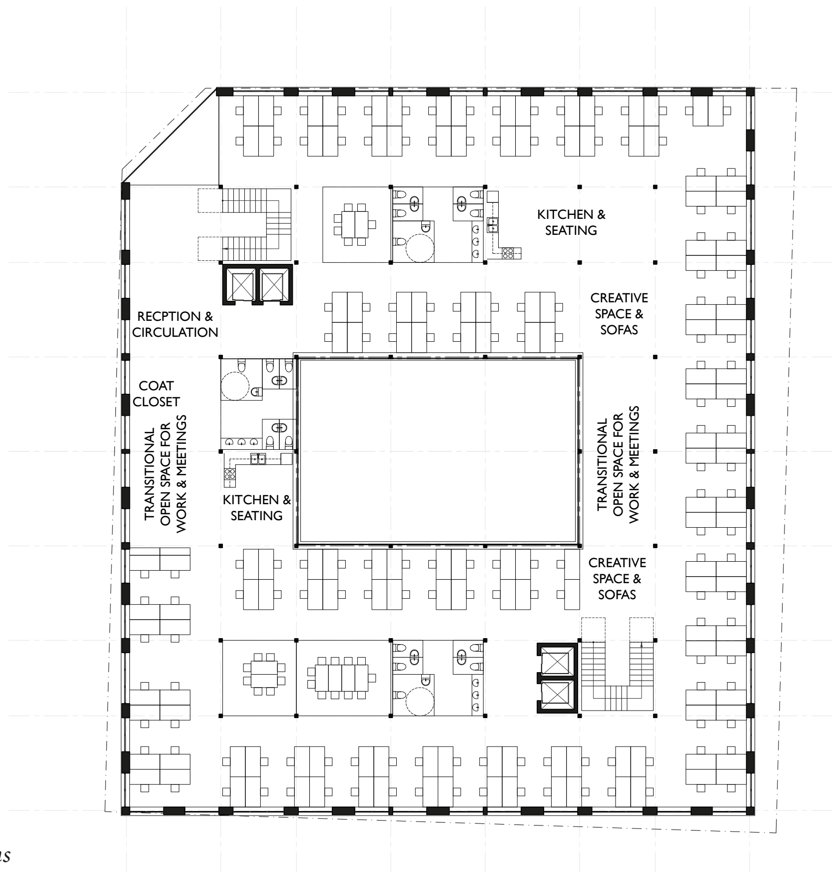
Figure 95: Ground floor plan



PLANS: FLOOR 2 - ROOF

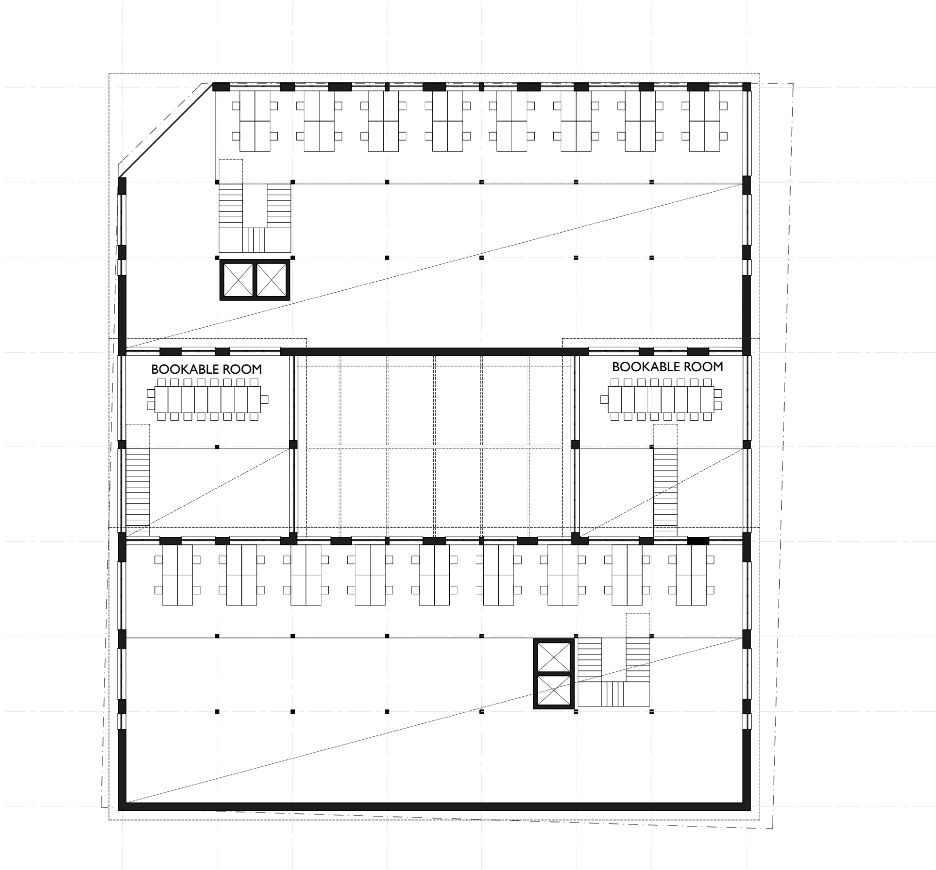


2nd Floor
Scale 1:400

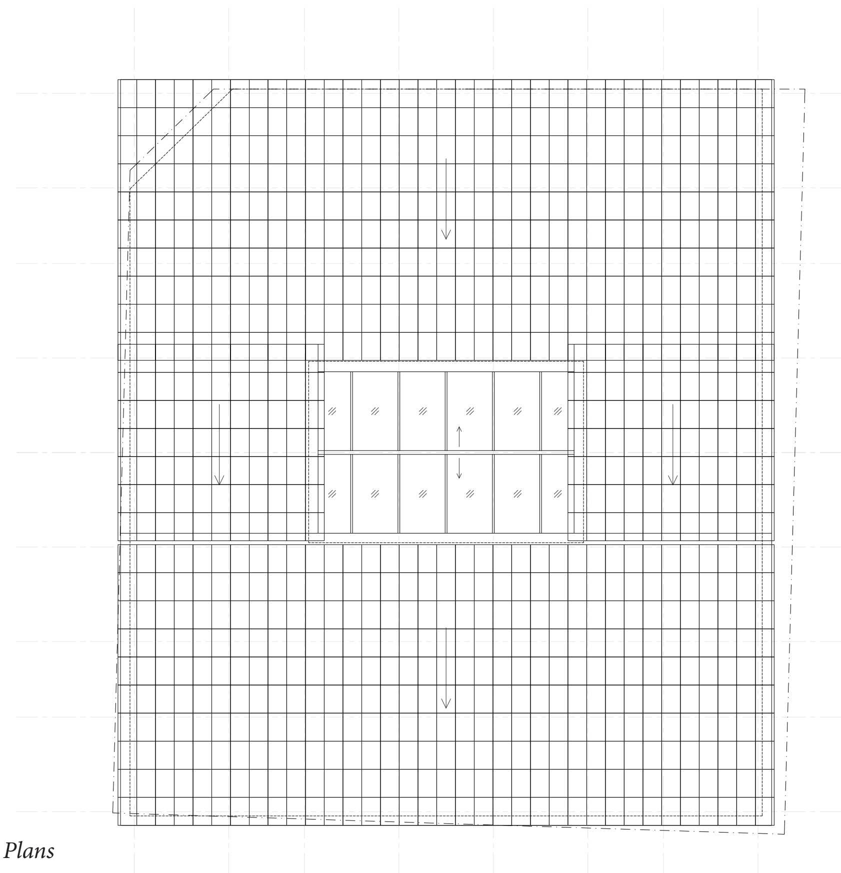


3rd Floor
Scale 1:400

Figure 96: 2nd-3rd Floor Plans



4th Floor
Scale 1:400



Roof Plan
Scale 1:400

Figure 97: 4th-Roof Floor Plans

ELEVATIONS

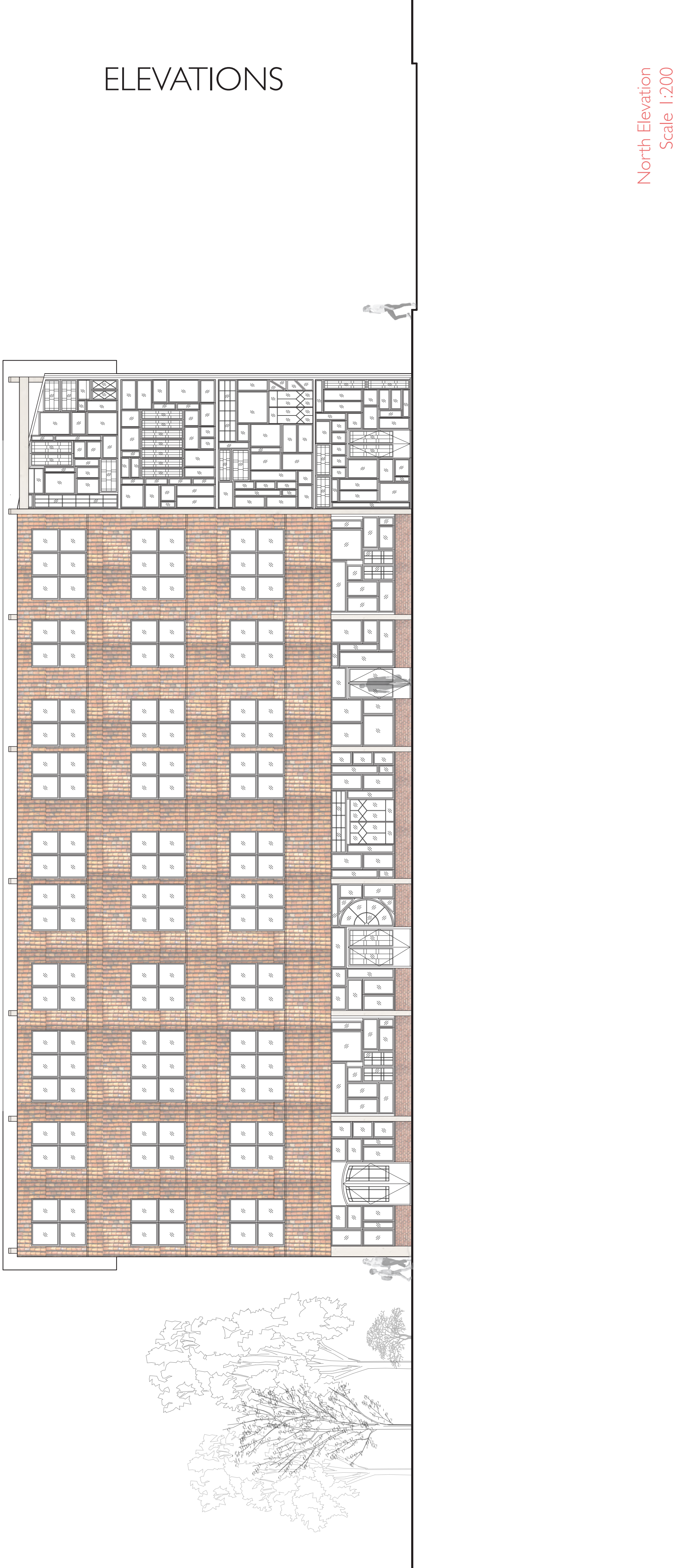


Figure 98: North Elevation

Figure 99: East Elevation

South Elevation
Scale 1:200

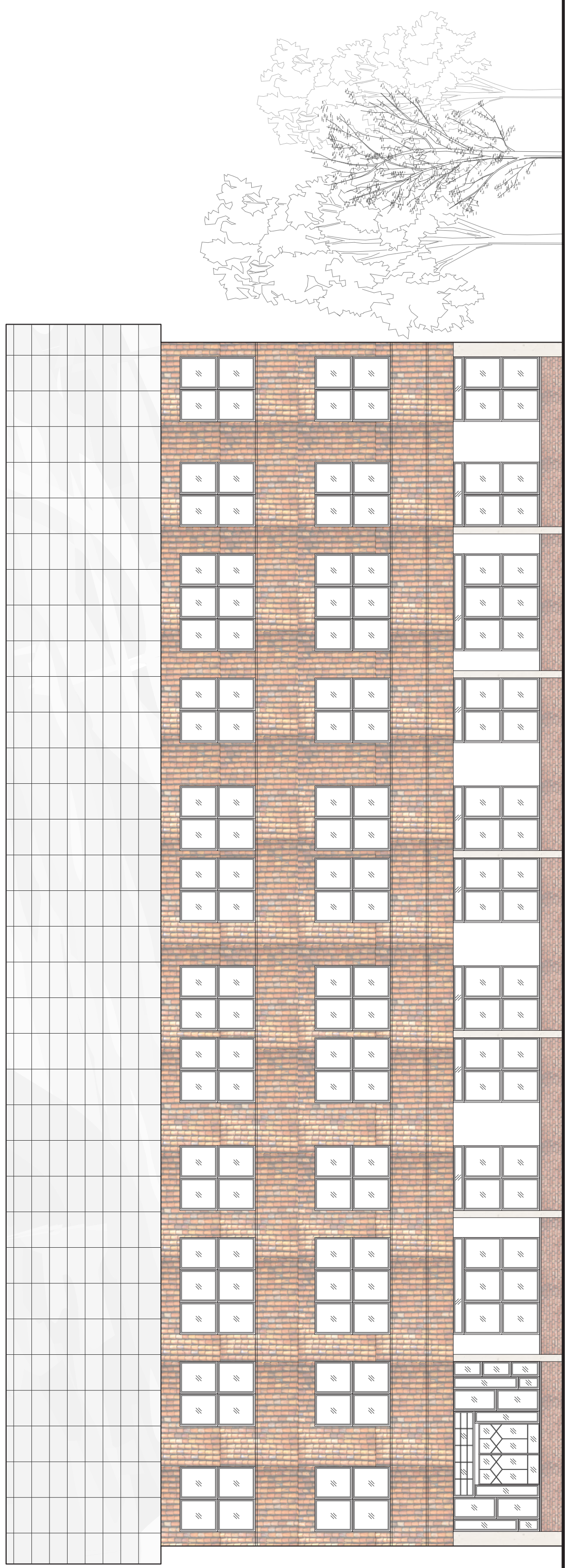


Figure 100: South Elevation

Figure 101: West Elevation

PART FIVE

Evaluation

Material Content -
Embodied Energy of the Structure -
Continued Workflow -
Possibilities & Challenges -
The New System -

EVALUATION

MATERIAL CONTENT OF THE BUILDING PROPOSAL

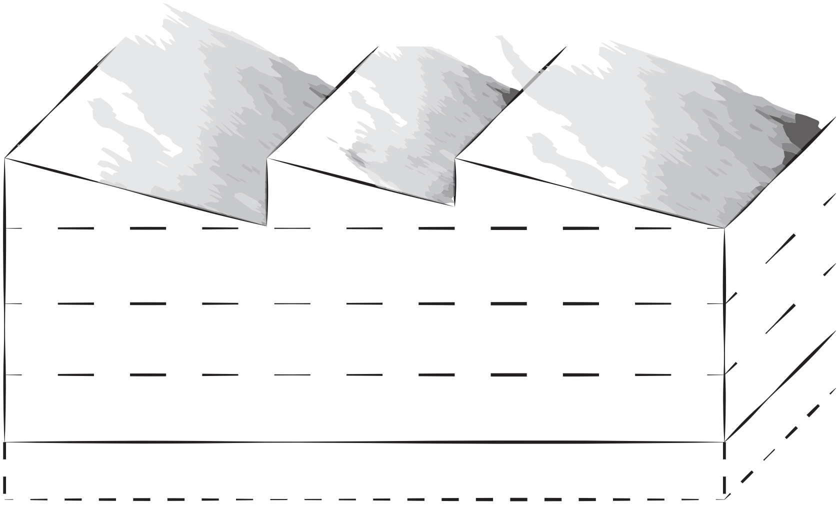


Figure 102: Proposed building sketch

Building Volume:	15607m³
Roof Area:	1310m²
Exterior Wall Area:	2843m²
Fenestration Area (ext.):	918.45m²
Fenestration Area (int.):	276.64m²
Total Floor Area:	3717m²
Number of Floors:	4
Staircases:	4
Structure:	946m of Columns (71)
	6411m of Beams & Joists
	420m³ required for wooden structure*
Building Shape Factor:	1.383 (Ratio Envelope : Floor Area)
Allowable Fenestration:	±34.4% = ±1768.5m²

*based on volume calculations performed in Rhino & AutoCAD

420m³ wood required for wooden structure

one 600m² wooden barn can provide

10%

of the wood volume needed for the building's structure

PERCENTAGE OF REUSE IN THE CASE STUDY PROPOSAL

While calculating all of the materials for the proposed building would be extensive task beyond the scope and time limits of this thesis, the structure itself can be formed by 10 wooden barns of the type inventoried in Vara by employing the glued timber element process from salvaged wood described on page 61.

One of the goals of the evaluation was to establish a percentage of the building that could be built from reused materials, but further material specification and detailing is necessary to make this determination.

The structure and skin combined hold the majority (±80%) of the structure's embodied energy. Using traditional timber construction joinery techniques, new metal connections in the structure can be eliminated to a great extent, allowing the designer to rely primarily on the glued solid timber in calculating the material needs and embodied energy of the structure. Solely reused materials have been identified for the skin and structure. Many reused materials can also be applied to the space plan layer. Therefore, over 80% of the building can be construction from reused material.

Approximately

>80% of building

can be constructed from reused material

EMBODIED ENERGY OF THE GLUED SOLID TIMBER STRUCTURE

DESCRIPTION

There are currently no economic incentives for material reuse. Implementing reuse as a environmental impact reduction strategy relies on an individual's or company's environmental motivations. However, the comparison of life cycle analysis calculations between a new building designed with reused materials and the same new building using new materials is a tangible method for exhibiting the benefits of reuse.

This thesis proposes a structure made from reclaimed solid timber that has been cut and glued to produce glued solid timber elements after collection. According to Kauschen (personal communication, March 2019), there is an industry-wide disagreement over how to calculate the life cycle values of reused materials. At this time, there is no standard method for producing life cycle analyses of buildings and materials that may continue to circulate in the economy following their first intended use, making true comparable analysis of the data impossible.

COMPARISON: REUSED VS. NEW GLULAM

See Figure 104 to the right for simplified calculations and comparisons. Spreadsheets used for the calculations can be found in Appendix III.

Glued solid timber from salvaged wooden barn structures
Given that some processing energy is required for the proposed method of glued solid timber production, an estimated value lower than typical glulam was used with the added transport footprint. Unsurprisingly, reused timber has a negative carbon footprint, better than new glulam.

Transportation of the timber from the collection points (dismantled buildings) to the Moelven wood factory in Töreboda, then to Mariestad has been estimated at approximately 100km.

New glulam
A new glulam structure of the same size (GL30c profile) is calculated as having a footprint of 34 976 kg CO_2/50 years.

In this case, transportation is calculated as coming directly from the Moelven factory, 18km from the construction site.

COMPARISON: STEEL VS. NEW GLULAM

To calculate a steel structure for the same building, the material in the steel structure LCA cannot simply be roughly estimated as a steel volume that is a fraction of the wood structure. Due to structural calculations differing between metal and wood elements, an alternate method of comparison is required.

A study done by Hassan & Johansson (2018) calculated and compared the economic and environmental aspects of glulam and steel structural options. In finding the corresponding glulam and steel loads carrying predetermined span lengths rather than comparing cross-sections that vary with the spans required, they showed the specifications and carbon footprints to the right (Figure 104). These numbers have been extracted as applicable to the thesis design's structural proposal.

For a span of 4m, The embodied energy of steel is ±1.6 times that of standard glulam wood when carbon storage of the wood is not factored into the calculations.

CONCLUSION

A building with a laminated wood structure has significantly lower embodied energy than the same building with a steel structure. Given the difficulty in calculating the embodied energy of reused materials, it is nearly impossible to compare the same structure between new and reused laminated wood, as all of the values contributing to the total embodied energy would be project-specific in a reuse situation.

One may assume that since no new material is procured when constructing with reused material, the embodied energy from resource extraction, transportation, processing, etc. would be significantly less than a construction consisting of new materials.

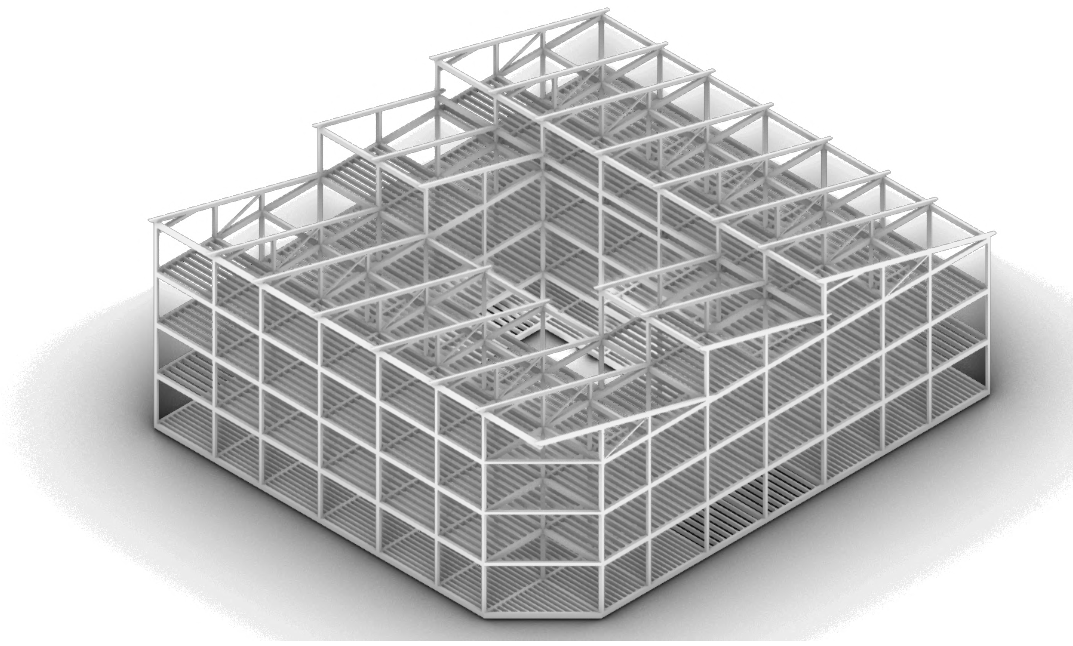


Figure 103: 3d model of the case study's proposed glued solid timber structure

COMPARISON: REUSED VS. NEW GLULAM

Glued solid timber structure (reused wood):

Material volume:	±420 m^3 wood
GWP:	-0.156 kg CO_2equv/kg
Stored Potential:	-1.5 kg CO_2/kg
Transport to/from Moelven Töreboda:	±100km
	= -29 368 kg CO_2/50 years

vs

Laminated wood structure (GL30c):

Material volume:	±420 m^3 wood
GWP:	0.191 kg CO_2equv/kg
Stored Potential:	-1.45 kg CO_2/kg
Transport to/from Moelven Töreboda:	±100km
	= 34 976 kg CO_2/50 years

Processing & local transport of reclaimed wood results in an overall

negative carbon footprint

COMPARISON: STEEL VS. NEW GLULAM

Laminated wood structure (GL30c):

Span:	4m
GWP:	63.9 kg CO_2equv/kg
GWP w/ Stored Potential:	-193.2 kg CO_2/kg

vs

Steel structure (estimated HEA200 profile)

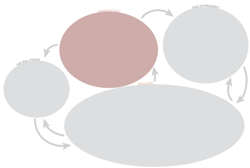
Span:	4m
GWP:	101.5 kg CO_2equv/kg
Stored Potential:	0 kg CO_2/kg

Embodied energy of steel is

±1.6x

that of standard glulam wood (w/out carbon storage inclusion)

Figure 104: Simplified life cycle analysis calculations & comparisons for the proposed case study structure



CONTINUED WORKFLOW (FUTURE STEPS)

The diagram to the right (Figure 105) adds to the initial workflow designed for and used in this investigation (p. 41). It shows future design steps that were beyond the scope and time limits of this thesis but that would come next should this project continue.

The future design and construction steps that would follow in a real built project have been gathered through the literary and interview research performed during the investigation process. However, as designing with and for reuse in the current complex system is still in its infancy, the workflow is subject to change through trial and error.

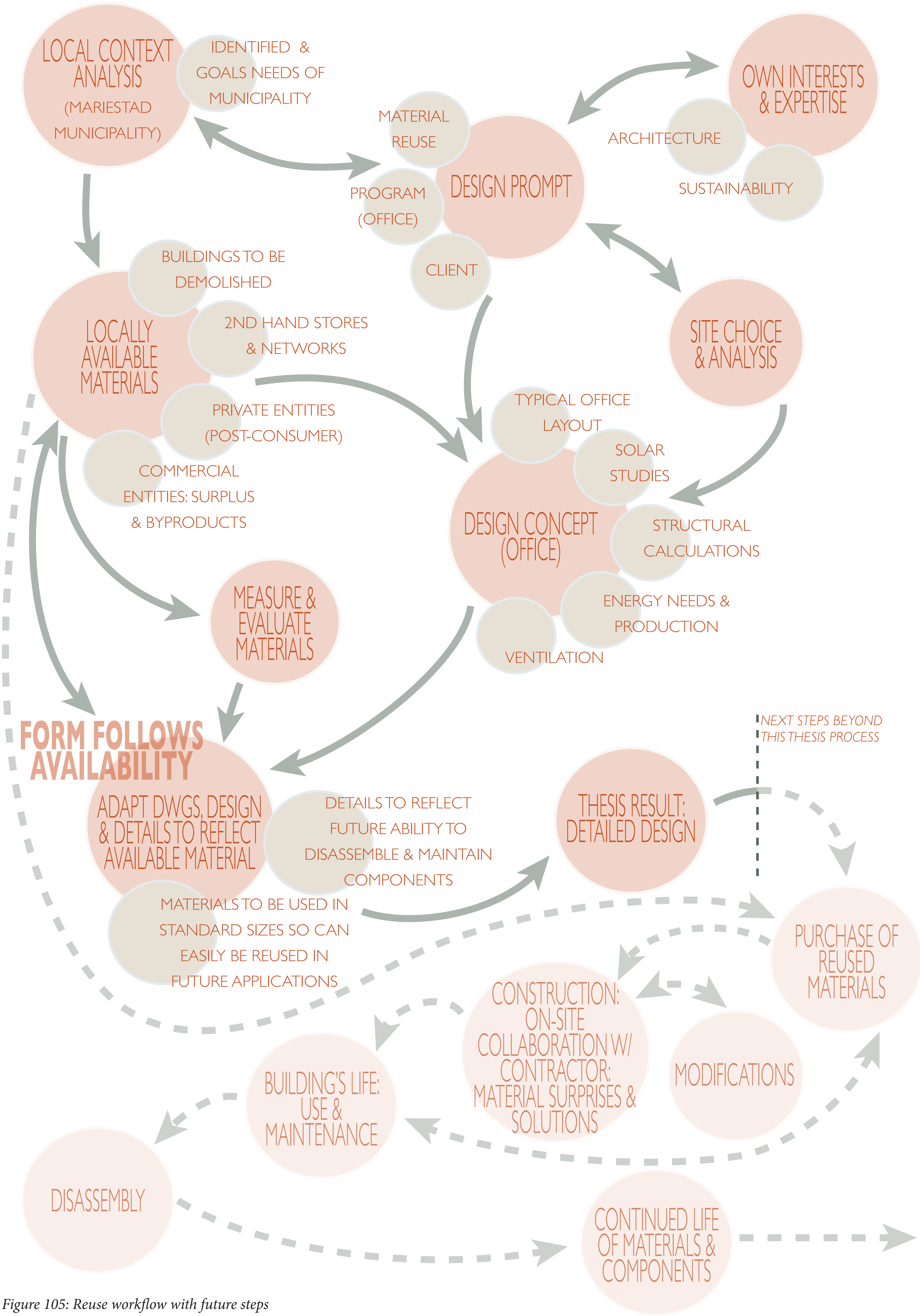
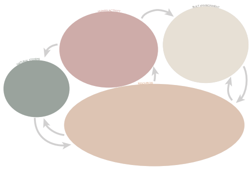


Figure 105: Reuse workflow with future steps



POSSIBILITIES & CHALLENGES

WORKING WITH MATERIAL REUSE IN CONSTRUCTION

With the onslaught of large-scale, machine-constructed buildings filled with highly processed, man-made materials of questionable dangerous chemical content, implementing material reuse is not so simple. Meeting with professionals working with these topics in the construction industry has resulted in in-depth conversation about the possibilities and barriers perceived and experienced when attempting to work or considering working with circular thinking. These conversations, along with the investigation research through literature studies and site visits, have provided a holistic understanding of the current situation and informed the design process.

The arrows in the diagram to the right connect possibilities and barriers of reuse that go hand-in-hand. The challenges of changing the system provide opportunities for creative solutions.

Summary

In general, two main points emerge in comparing the pros and cons:

- Implementing reuse will require large-scale systemic change
- The environmental and aesthetic benefits outweigh the drawbacks of the economic and status quo factors

POSSIBILITIES

Humans are attracted to beauty; new forms of beauty can be created by reusing old materials.

- Objects / components / materials are imbued with history and stories of previous lives.
- Reuse maintains or increases cultural value.
- Beauty of aging: It is nearly impossible fake surface patina from naturally aged materials.
- A loved building is protected by the people, extending its lifetime & increasing its sustainability.

Material passports can support informed decision-making by providing accessible material history and content to minimize uncertainty and reduce the material testing process.

There are many used materials available on the market.

Reuse consumes less energy and prevents waste production.

Planning for and interdisciplinary coordination from conception to completion of the project.

Ongoing research in creating guidelines / standards for proper material inventory, deconstruction, and waste / resource management processes.

Ongoing standardization of material inventories & building stock data will help organize & balance the supply & demand of reused materials.

New design with reuse also allows for design for future reuse to maintain material value.

Reuse can close & slow down the materials cycle. A building's grave should not be then end of the life of its components.

Use temporary public building projects to test building methods and techniques, as well as garner public support. Such testing can help establish new logistics frameworks and provide the basis for a reuse economy.

In designing prior to finalization of construction components, designing in standard increments (ex. 60cm) can simplify material selection & collection with approximate sizings.

Look beyond materials available in the construction industry & mine other waste streams in sourcing materials.

CHALLENGES

No clear economic benefits at this time.

- Just the re-packaging and transport of used materials cost more than the purchase and shipment of new.
- Immediate investment costs are high.

No supporting standardized logistics system for reuse

- No consistent material flow of supply & demand
- Material availability is variable and unreliable.
- Many small, unrelated marketplaces without an efficient knowledge sharing network.
- Only small-scale projects employ reuse; issue of scale
- Inconsistency in data collection & reporting

Provisions for material reuse require increased time and the additional steps of material inventory and waste / resource management planning prior to the deconstruction process (rather than demolition).

Contractors are not trained in deconstruction; staff must have the ability & capacity to carefully disassemble and sort deconstructed materials.

Must support decision-making with transparent & accessible building & material data.

It is difficult to verify used material composition and quality, especially in the case of self-reported materials on current online marketplaces. There is no third party verification system.

Standards have changed over time. Old, salvaged materials from different eras often do not meet higher contemporary standards, such as in acoustic and thermal insulation.

Increased risk & liability: without the ability to track material make-up and quality, reuse increases client and contractor risk and liability; it is difficult to procure insurance, building department, and fire standard approval.

Need education on reuse for architects, building owners, demolition firms, lawmakers, and insurance providers.

Develop a common language about circularity, life cycles, & embodied energy to promote conversation.

Designing for reuse requires use of high quality materials to withstand wear of assembly & disassembly processes

Transportation increases materials' embodied energies; location-specific material data is required for informed environmental impact evaluations.

Figure 106: Summary of possibilities & challenges resulting from the research investigation

THE NEW SYSTEM
INTERVENTIONS & FUTURE VISION

INTERVENTIONS IN THE EXISTING SYSTEM

As a result of the research, potential interventions in the existing system were pinpointed, which could make reuse possible at a larger scale and make it available to common practice. In Figure 107 to the right, the proposed interventions and their relationships to other system variables are highlighted, indicating the effects of changes on the entire system. By applying changes to significant system leverage points, massive change can occur because all variables in the system are connected.

VISION: THE PROPOSED SYSTEM FOR BUILDING MATERIAL REUSE

Figure 108 on page 102 shows the vision for a future system that supports material reuse on a large scale, made possible by the proposed interventions into the existing system seen in Figure 107.

The new local reuse system will:

- Reduce raw material extraction and production, thereby reducing:
  - CO_2 emissions
  - Energy usage
  - Raw resource extraction
- Reduce transportation needs
- Strengthen sense of local identity & proclivity towards a love of local architecture

CONCLUSION

As stated in Part I, the goal of introducing these interventions is the reduction of the construction industry's negative environmental impact through implementation of material reuse in a circular economy.

Based on the existing system identification and analysis of needed interventions, it is clear that implementing change relies heavily on educating people about how to work circularly, standardizing pre-demolition audits with material inventories (personal communication, BAMB Conference, Ehlert, February 6, 2019), and making information about the buildings and materials transparent and available to everyone involved so that companies and individuals alike can make informed decisions.

Summary

To make reuse possible on large scale:

- Provide education on working circularly to architects, contractors, & lawmakers
- Standardize pre-demolition audits with material inventories to contribute to the larger catalogue of material in the building cadastre
- Increase transparency & availability of information to support informed decision-making
- Plan ahead for a circular future using the data and tools provided

Interventions In The Existing System

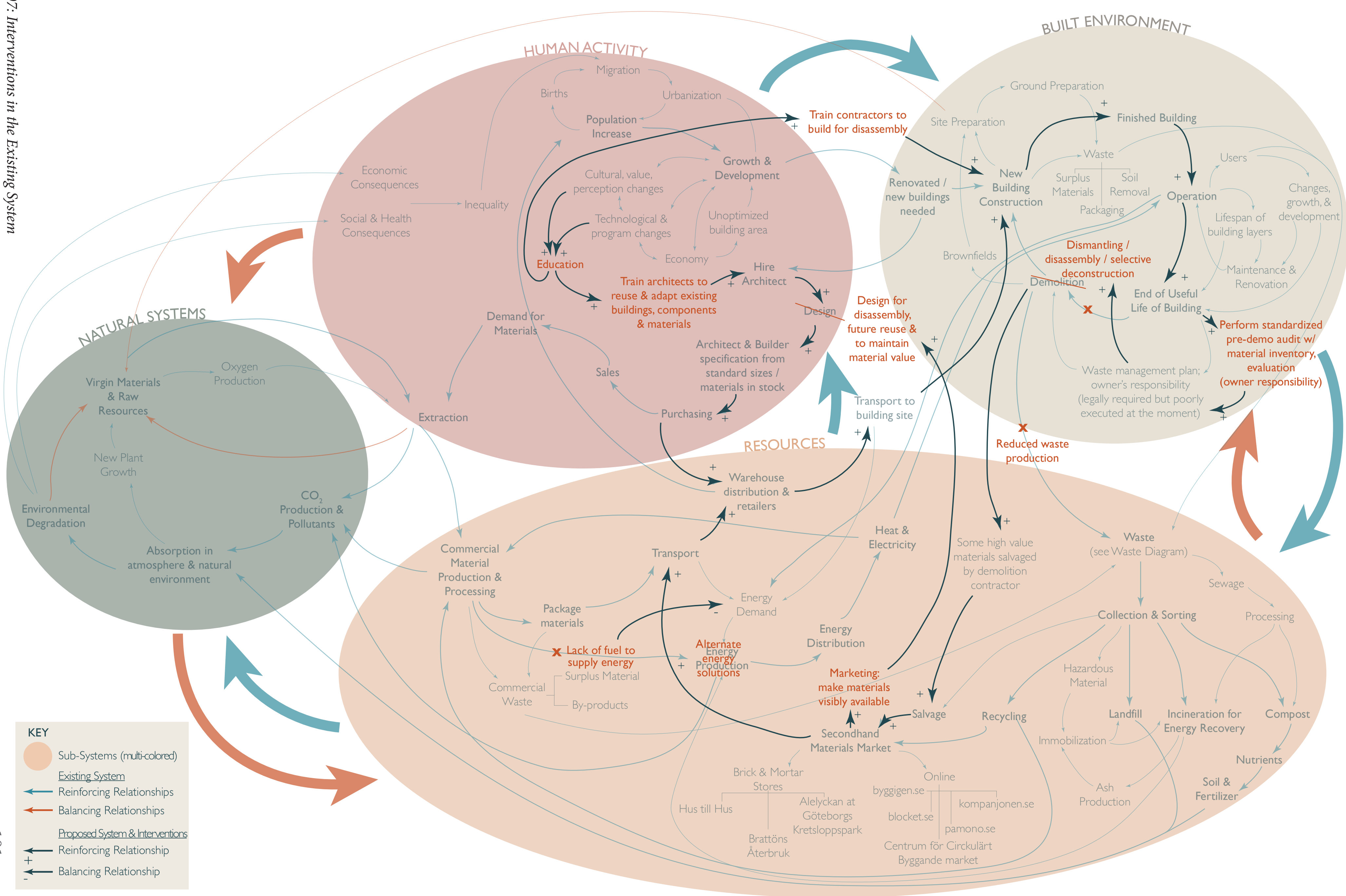


Figure 107: Interventions in the Existing System

Vision: the Proposed System for Building Material Reuse

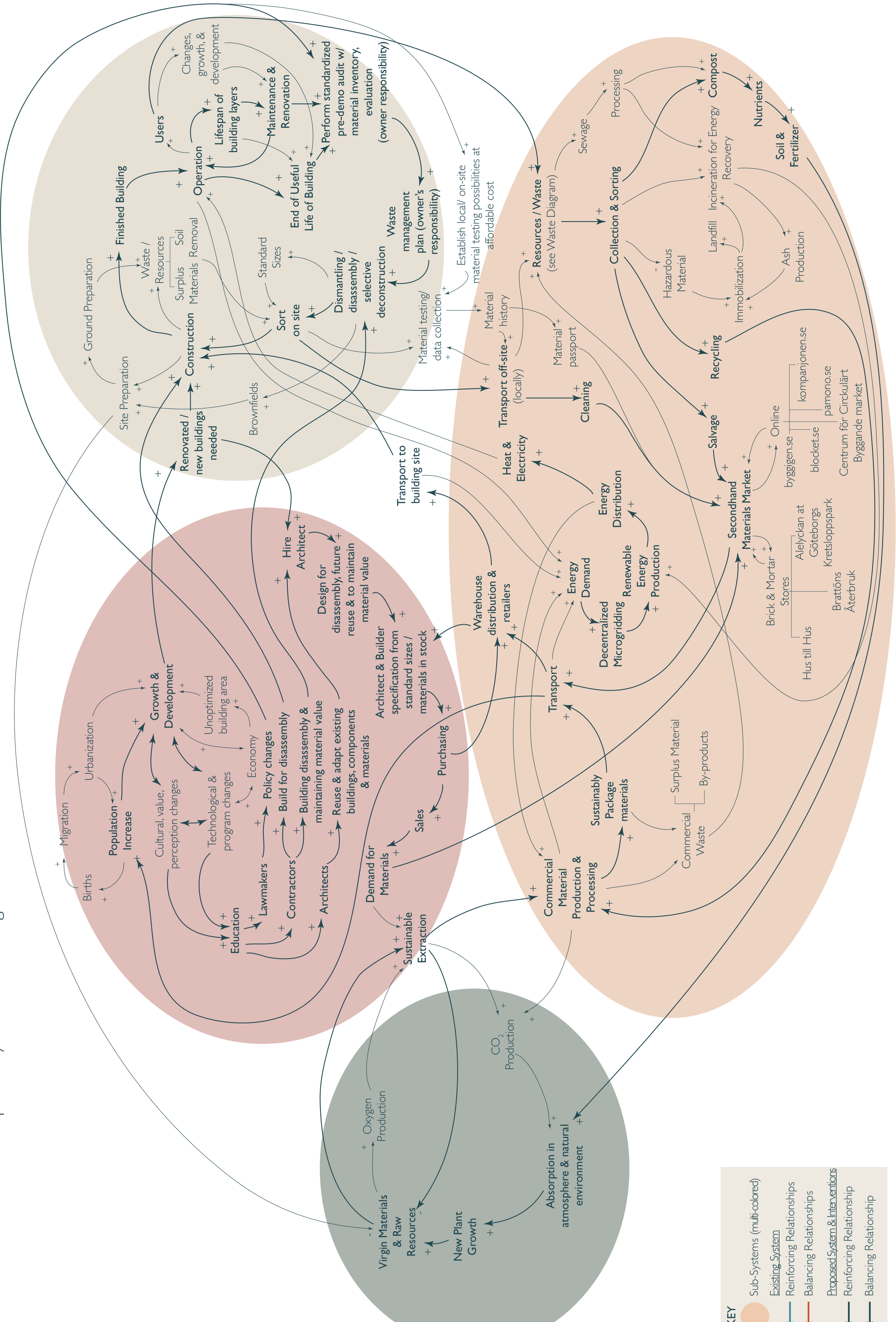


Figure 108: The New Proposed System

PART SIX

Conclusion
Summary -
Personal Reflection -
References
Figures

CONCLUSION

IN SUMMATION OF THE WORK

This thesis investigation has discussed the questions below in order to contribute to the larger discussion of sustainability and climate impact reduction in the construction industry. While some possible solutions for systemic change and technical methods of working with reuse have been proposed, a number of issues have been mentioned but left open ended for further research and discussion.

1) How can an architect rethink the existing wasteful linear materials system by designing for the long term, employing circular design as a guiding concept?

The ways in which architects' decisions in the built environment have far-reaching effects. Should architects begin to work with reused materials in their design, a workflow and a number of design strategies have been proposed in this thesis that may guide them in that endeavor. The case study and design proposal are an example of the outcome that resulted from employing these principles; however, the main message is that architects must learn to adapt their designs to that which is available in local existing resources, bringing to light the value and beauty of those materials and the forms that they inspire.

2) How can materials salvaged from their first use be evaluated, collected, and made available to designers, contractors, and private individuals to encourage material reuse as a common practice in construction and renovation?

This thesis proposes a material inventory and selection process (ie. choice of materials with least hazardous chemical content possible chosen) designed specifically for this investigation but based on work referenced mainly from the Danish architecture offices of Vandkunsten and Lendager Group. To perform complete material inventories is a time-consuming process but should be implemented as a common practice when building owners file for building renovation or demolition permits to assemble a catalogue of known materials, their content, and their next uses and destinations in their useful material lives.

There is a need to track and collect building materials used, amounts, material content, etc. in a large-scale material database to plan for future reuse potential. By keeping track of this information in an accessible database, efforts towards creating a circular economy may become organized and coordinated. The wide distribution of smaller, unconnected waste handlers, recycling entities, and secondhand material retailers that is prevalent in the current system creates inefficiences in material flow and prevents potential material reusers from knowing of and being able to make use of existing materials circulating in the system. Due to the existing conditions, the final design proposal of the thesis relied on sourcing from a variety of sources, which would cause increased time and effort for sourcing construction materials on behalf of the contractor in a real construction scenario.

Additionally, interventions in the existing system have been proposed to enable and support material reuse across the industry. Changes in the system related to the construction industry would inevitably change the workflow of designers, contractors, and all related actors when designing with and for reuse. Not only would the workflow change for the typical trades involved in the construction industry but a transition to circular material flow could create new jobs to support the industry.

3) How can building materials and components be connected and assembled such that they can continue their lives after each respective use without using value?

The proposed design strategies provide principles of circularity that should be employed when design for future building material and component reuse. These include designing in layers (for maintenance), specifying standard dimensions, use of high quality materials, and detailing for disassembly.

While some technical solutions are proposed for material assembly, more technical detailing showing design for reuse (disassembly) could be developed. To keep materials in the circular economy, this is a crucial aspect.

PERSONAL REFLECTIONS

With this work, I have only scratched the surface of the topic of material reuse in buildings. If reuse were simple, it would already be implemented as a climate impact reduction strategy. The challenges of reusing materials in construction, including the lack of logistical systems, accessible and comparable data, knowledge exchange, and supply and demand, require a change of societal perceptions and values, as well as supporting business infrastructure, policies, and practices across the local, regional, and national levels.

At this point in time, it is seems impossible to create a building fully out of reused building materials on a small scale, although the used materials could be sourced for the majority of the building. It is important to prioritize reasonable reused materials compared to that which is better suited as a new material (to be designed for future disassembly and reuse), upcycled, or transformed from other categories of "waste" or by-products. However, should reuse become a more viable strategy in reducing the construction industry's climate impact, it must be possible to practice material reuse at a large scale.

There are many individuals, firms, companies, and researchers working directly with reuse and with related topics. Many of these are stand-alone projects or entities; in creating a unified network of resources, they could build on each other's work and generate new ideas. The collection and amount of information and work to consider when researching this project was overwhelming, especially considering the system within which the construction industry operates and the unlimited interconnectivity of each variable.

There is much more work to be done in the realm of material reuse in the construction industry, and architects are just the people to lead the charge. It is a very exciting topic that invites interdisciplinary experimentation in material, technological, and design solutions. While many challenges lie ahead, design with and for reuse has a bright future in the construction industry.

The work performed in this design proposal is an example of a site-specific solution in Mariestad, Sweden, and is itself a one-off project given that material reuse in construction is not a common practice. Despite the issue of scale, a pilot project such as this can provide an example of the possibilities, potentially sparking interest in supporting future reuse.

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ADDITIONAL RELATED WORKS

PROJECTS

- Aardehuis, Netherlands
- Circle House (Copenhagen)
- Circular Retrofit Lab (Brussels) & Buildings as Material Banks (BAMB)
- Effekt's Regen Villages - https://www.effekt.dk/regenvillages
- IVL Svenska Miljöinstitutet, Göteborgskontoret by IVL Svenska Miljöinstitutet, Tenant & Partner, Chalmersfastigheter and Spectrum Arkitekter (Göteborg)
- La Ferme du Rail by Grande Huit Architects
- La Récyclerie by OPA (Office Parisien d'Architecture)
- Pavilion Circulaire by Encore Heureux
- Wasteland exhibit by Lendager Group
- Zero Waste Bistro by Linda Bergroth

ORGANIZATIONS

- BAMB (Buildings As Material Banks)
- Brattöns Återbruk - http://www.brattonsaterbruk.se
- Bygg Igen - http://byggigen.se/Default.aspx
- Centrum för Cirkulärt Byggande - https://ccbuild.se
- Fred Sanders – working with retrieved material depots
- G. Shiller and T Lützkendorf – working with material flows
- GXN
- Harvest Map (Netherlands & Detroit) - https://harvestmap.org/
- Kompanjonen - https://www.kompanjonen.se/#
- Lendager Group
- Opalis - https://opalis.be/en
- Orust Kretsloppsakademin
- Malmö Återbyggdepå - http://www.malmoabd.se/om-malmo-aterbyggdepa/
- Material District - https://materialdistrict.com/material/
- SuperUse Studios
- Recyklujmestavby.cz - Czech website, with suggestions on how to disassemble and reuse building parts
- Vandkunsten A/S

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FIGURES & TABLES

APPENDIX I

Reflections & summaries of:
Interviews, study visits, & discussions

INTERVIEWS, DISCUSSIONS & STUDY VISITS: LIST

TUTORS

John Helmfridsson	Chalmers University of Technology & Wingårdh Arkitektkontor
Anita Ollár	Chalmers University of Technology

INTERVIEWS & MEETINGS

People	**Organization**	**Date**
Shea Hagy	Chalmers University of Technology Göteborg, Sweden	January 21, 2019
Mats Torring	Stena Metall, AB Göteborg, Sweden	January 21, 2019
Carina Loh Lindholm	IVL Svenska Miljöinstitutet Göteborg, Sweden	January 28, 2019
Lasse Lind	GXN Copenhagen, Denmark	January 29, 2019
BAMB Conference	Brussels, Belgium	February 5-7, 2019
Erik Berg Christian Rubell Sara Wester Peter Gustafsson Ulrika Lindh Caroline Laudon Karin Heden Valter Samuelsson	Egnahemsfabriken, Inobi Egnahemsfabriken, Hakenäsetsbyggnadsvård Västfastigheter Västfastigheter Nääs Slöjd & Byggnadsvård Nääs Slöjd & Byggnadsvård White Arkitekter Hus till Hus Sahlgrenska, Göteborg, Sweden	February 11, 2019
Ida Toll	Architect @ Nudie Jeans Göteborg, Sweden	February 12, 2019
Anne-Mette Manelius Katrine West Kristensen Salma Zavari Jan Schipull Kauschen	Vandkunsten Copenhagen, Denmark	March 5, 2019
Petter Reuterholt	Material ConneXion Skövde, Sweden	March 6, 2019
Christer Owe	Orust Kretsloppsakademin Göteborg, Sweden	March 8, 2019
Florijn de Graaf	Sustainable Energy Systems Engineer (Spectral) Amsterdam, Netherlands	March 11, 2019
Arkitekturgalan 2019	Stockholm, Sweden	March 19, 2019
Marine Kerboua	M.Arch École d'Architecture de Paris-Belleville (Intern at Grand Huit Architects) Paris, France	March 30, 2019

STUDY VISITS

People	Organization	Date
“Wasteland” Exhibit	Lendager Group Värnamo, Sweden	January 19, 2019
BAMB Conference	Buildings as Material Banks Brussels, Belgium	February 5-7, 2019
Circular Retrofit Lab	Buildings as Material Banks Brussels, Belgium	February 6, 2019
Sahlgrenska Demo Bldg w/ Egnahemsfabriken & Hakenäsetsbyggnadsvård	Sahlgrenska Hospital Göteborg, Sweden	February 11, 2019
Greenhouse	Botaniska Trädgården Göteborg, Sweden	February 19, 2019
Hus Till Hus	Alingsås, Sweden	February 23, 2019
Material ConneXion	Skövde, Sweden	March 6, 2019
2 Wooden Barns	Vara, Sweden	March 8, 2019
Arkitekturgalan 2019	Stockholm, Sweden	March 19, 2019
Kretslopparken Alelyckan	Göteborg Stad Kretslopp & Vatten Göteborg, Sweden	March 23, 2019
La Ferme du Rail	Grand Huit Architects 2 Rue de l’Ourcq 75019, Paris, France	March 30, 2019

INFORMAL DISCUSSIONS & EMAIL CORRESPONDENCE

People	Organization	Date
Hanna Gerhardsson	IVL Svenska Miljöinstitutet	January 28, 2019
Linnea Lindkvist	HiFab	January 29, 2019
BAMB Attendees:		February 5-7, 2019
Mark Gorgolewski	Prof. / Chair @ Ryerson University	
Urszula Kozminska	Ass. Prof. @ Aarhus School of Architecture	
Anne-Mette Manelius	Architect @ Vandkunsten	
Martha Lewis	Architect @ Henning Larsen	
Camilla Sjögren	Ronneby Kommun	
Erik Berg Christian Rubell	Egnahemsfabriken Hakenäsetsbyggnadsvård	February 11, 2019
Ida Röstlund	Chalmers University	March 14, 2019
Thomas Johansson	Moelven Töreboda AB	April 15, 2019

INTERVIEWS, DISCUSSIONS & STUDY VISITS: SUMMARIES & REFLECTIONS

SHEA HAGY @ CHALMERS UNIVERSITY OF TECHNOLOGY

Recommendations from Shea while discussing the thesis plan and objectives in the first week of the semester:

- *Use Swedish standards to build in modules (the size of a plywood sheet).*
- *Define the terms I use, including determining the boundaries of the investigation and material use: post- vs. pre-consumer vs. revived vs. bio-based materials. I should categorize and define the materials to focus on.*
- *Shea recommended I reach out to the module contractor to ask questions about training, feasibility, and logistics in prefab construction, especially concerning reuse integration.*

MATS TORRING @ STENA METALL

Mats was very invested in all of our topics. He has worked with reuse all his professional life, including writing a thesis on the topic during his time as an engineer at Chalmers. He recommended that we not get bogged down in reality but to use our imaginations in our thesis work.

He started the online reuse market platform, Bygg Igen, in the 90s, but it has not been updated in a long time. Many of the questions we are still grappling with today have been discussed at least since the start of his career (as evidenced by the magazine he shared with us in the lower right, dating back 22 years ago), but nothing has yet been solved. However, we now have digital tools that can help make these transformations a reality.

All material in the Swedish society essentially goes through Stena.

Mats wants to know what kinds of products and architectural expressions we can create from waste, recycling, and reuse. He created his own company (Repur) where they crush old used products, binding them together to create composites (with polyurethane), but he has no use for many materials produced; he needs a designer to find uses for them. Upon direct contact with one of the composite product samples, two members of our group experienced some skin irritation. I would not use these in an interior space where humans could be exposed.

He recommended that we look at what comes from the products they receive both as entire components as well as halfway through the post-consumer recycling or disposal process, such as what one can do with sections of wind turbine wings (of which they have many).

Stena Metall's office

Construction magazine titled Building Reuse, 1997

CARINA LOH LINDHOLM @ IVL SVENKSA MILJÖINSTITUT

Much of the information that I am searching for regarding quantities of hours, cost, materials, etc. can be found in the reports IVL has published on their office renovation.

The Göteborg office is the first of 2 IVL offices renovated using reused materials. All work consisted of interior furnishings and fixed interiors, including flooring, cabinets, acoustic panels, doors, and furniture. Not everything could be reused; 70% of the loose furnishings and 50% of the fixed furnishings were reused.

Material inventories were conducted by the architect, acoustic consultant, etc. to see what could be salvaged. Old acoustic ceiling panels were reused in both ceilings and on interior wall partition coverings, but in certain areas, such as the main conference room, where higher sound insulation values were required, the old panels did not provide enough insulation and had to be replaced with new.

Per Carina, only one bathroom required a larger door and door opening due to updated accessibility regulations. The bathroom faucets and toilets were reused but interior fittings were replaced for increased water savings.

When refurbishing the existing furnishings, most items remained on site to avoid transportation.

The architect and contractor did not feel that the work for this project took more total time, but the time used was distributed in a different way than a new building or renovation might normally be. The inventory (by the architect) took a much longer time than it typically would. Deconstruction took a bit more time than demolition, but they saved time and money on avoiding material disposal and removal from site.

The office layout changed from individual offices to an open floor plan with flexible work spaces (old glass partitions were reused in the new design). Most people like the new layout but some preferred their own offices. All like the new interiors. It is a mix of old and new, but it is impossible to determine which is which.

See the report on circularity in the interior furnishings industry by RISE (Cirkulära Möbelflöden: Hur Nya Affärsmodeller kan Bidra till Hållbar Utveckling inom Offentliga Möbler), which compares the carbon footprint caused by transportation vs. renovation or refurbishment.

IVL rents the space from Chalmers Fastigheter, so building owner, the architects, and the contractor had to be convinced of the environmental benefits before proceeding with a project involving reused materials. IVL had not done such a project before, so there were no economic comparisons that could be provided at the time. The report published by IVL at the end of 2018 provides quantitative information for both the Göteborg and Stockholm offices.

Following the successful office renovation, they are working on an ongoing renovation project with Vasakronan and White Architects. The report is ongoing.

Generally it seems that smaller building firms and owners are requesting reused materials (scale issue).

Currently, IVL is working on a reused materials marketplace online with Centrum för Cirkulärt Byggande. It will go online later this spring. Similar to Bygg Igen and the Harvest Map websites that came before, this is a self-reported marketplace. Sellers note the quantity, quality, etc. In contrast to the others, if available, they note any dangerous material content. These properties are neither checked nor controlled by an external entity, nor do IVL or CCB take responsibility for the products sold and purchased on the platform. The inability to control or check the quality of the product from a distance is a hindrance in the reuse process.

For calculations regarding the carbon footprint and cost, direct questions to Hanna. Look at Kompanjonen (contact Per Håkansson); they collect and resell used loose furnishings on the reuse market. It seems that Kompanjonen is better at buying than selling the reused materials.

LASSE LIND @ GXN / 3XN'S OFFICE IN COPENHAGEN, DENMARK

In working with sustainability and circularity, you have to define your chosen hierarchy. In that I have chosen to work with the layers of the building that have the longest lifespans (referring to Stewart Brand's "Shearing Layers" diagram: the structure, skin, and space plan layers).

In terms of the carbon footprint of a building, the structure itself, especially when using concrete, encompasses approximately ±80% of the building's carbon footprint / embodied energy. It is unlikely that one would disassemble a building structure as compared to the interior walls, which should be designed for disassembly, as they have a shorter lifespan. Evaluate the sustainability of your design by determining the ranking and hierarchy you want to consider.

- *Surfaces: Directly off-gas and affect user health and indoor environment. Chemical composition is highly important.*
- *Structure: Long life span required. Embodied energy as a determining factor rather than chemical composition.*

In regard to innovation (of materials and building components) in the company, GXN always works in collaboration with other entities, such as the Danish Institute of Technology. The only way for the research portion of the firm to be economically feasible is to:

1) *dedicate a team to working on new products*
2) *receive research funding from outside agencies (both public and private funds, such as the EU, Danish government, and private foundations)*
3) *collaborate with other experts, such as chemists and material production companies, as architects do not have chemical and production knowledge or facilities.*

Not all materials GXN works with can be invented on demand for ongoing projects. They often look to existing upcycled or recycled products already on the market to specify or apply in new ways (such as in the Circle House). While there is a demand for sustainable products on the market, most companies want to minimize risk, so it is difficult to approve a new product.

In terms of clients, GXN / 3XN has built a profile or agenda that allows them the luxury of working with clients and products that are in line with their sustainability mission.
Regarding the reuse of products (and recycling) you have to think backwards: survey what you have and create a form or design from it. The issue of scale is fully dependent on material availability and ease of access. Without a strong material reuse flow with supply and demand, including a usable platform for connecting materials and users, it is difficult.

Lasse stated that at this point in time, it is impossible to create a building out of fully reused materials and advised that I "pick my battles" and determine that which is reasonable as reused material and what could be new (designed for future disassembly), upcycled, or transformed from other categories of "waste" or by-products.

There is a question of how you match materials to potential users and the need to change the value chain (rather than crushing a material that has reached the end of its first useful life, using it as landfill, how can you use it in such a way that retains or increases its value?). This could mean an increase in monetary value of certain products for actors such as demolition companies.

Regarding material specification, use materials that already fulfill the requirements of sustainable certifications or ask suppliers and sub-suppliers for detailed information on things such as chemical composition if EPDs are not available.

Samples of materials developed in collaboration with GXN

GXN / 3XN Office

KICK-OFF MEETING: BUILDING MATERIAL REUSE STRATEGIES FOR FUTURE DEMOLITIONS & RENOVATIONS AT SAHLGRENSKA UNIVERSITY HOSPITAL CAMPUS IN GÖTEBORG, SWEDEN

Västfastigheter, the company that owns the Sahlgrenska Hospital buildings, is planning a huge number of changes to the built environment of the hospital campus. In addition to new construction in the immediate future, a large number of buildings, some of which date back to the late 1800s, require renovation or complete removal in order to meet the hospital's modern needs. The scale of this demolition and construction project will make a huge amount of material available, which, if properly evaluated, inventoried, and carefully unmounted, could be reused in any number of future construction projects, on the Sahlgrenska campus or elsewhere in Sweden. This kick-off meeting was a gathering of professionals from a range of companies in Västra Götaland interested in material reuse and building conservation, who shared their backgrounds, experience, and interest in supporting material reuse exchange in the region.

In the summer of 2018, a Sahlgrenska building was demolished with only a small handful of the brick cladding material being salvaged and sent to Hus till Hus for cleaning and reselling. The majority of the building's old brick facade was dumped in a landfill in Landvetter to avoid waste disposal fees. Not only the brick, which was of high quality according to Valter of Hus till Hus, but most of the other building materials were designated for waste or recycling piles when material reuse would have been a less energy-consuming option, giving continued life and cultural value to the materials that had served years in this important institution. White Arkitekter had even provided a material inventory for this building in hopes that some material could be salvaged, but according to Västfastigheter's project manager, the timeline between demolition permit approval and the actual demolition start date was too tight, not allowing time for coordination of careful material removal. Additionally, the demolition work took place during the summer holiday months when many were on vacation. While this was advantageous to limit disturbance of Sahlgrenska hospital's employees, other building companies, such as Hus till Hus, were understaffed and could not accept large quantities of material.

The above instance is an example of not involving groups who can collaborate on a demolition plan with proper time management from the beginning of the process. If an inventory and plan had been formed when demolition and construction talks had begun, a bid for a contractor who would carefully deconstruct the building with the goal of salvaging materials could have been requested, the material could have been transported from site, sorted and sent to the proper channels for redistribution. Both Hus till Hus and Egnahemsfabriken stated that they would have gladly received the usable materials from this building.

While Västfastigheter's project manager cited time constraints and economic benefits as the largest hurdle from his perspective in regards to selective deconstruction for future material reuse, other meeting participants discussed a lack of a material reuse network or infrastructure in Sweden. They did not know where to find a demolition company who had the ability or capacity to carefully deconstruct a building (if not on a small scale where Hus till Hus or Egnahemsfabrikens volunteers could go in themselves and selectively remove certain components as they saw fit), nor is there a widely available market or warehouse where the materials could be sold. The lack of material reuse channels might soon be solved with Centrum för Cirkulärt Byggande's online marketplace, opening in 2019. Additionally, they did not know where to begin, expressing a need for guidance in the work process of creating a proper material inventory, deconstruction, and used material removal plan, or waste management plan.

After hearing from a variety of actors in both Göteborg and at the BAMB conference, it seems that larger, more coordinated efforts to build a material reuse network to support both the supply and demand are direly needed. Communication in the smaller scale efforts scattered throughout Europe needs to be streamlined and education on this topic for architects, building owners, demolition companies, and lawmakers must be provided. In order to support this network, material reuse must be more widely available at a larger scale than individual one-off projects. The current lack of logistics and organization on a large scale seems to be the greatest barrier in moving forward at this stage.

In addition to the upcoming demolition of Sahlgrenska buildings, Västfastigheter will also be involved in the upcoming demolition of a large greenhouse at Göteborgs Botaniska Trädgård. I will visit the sites (both the hospital and garden buildings) and plan to propose uses for some of the materials in my thesis design project.

Greenhouse at the botanical gardens

Caroline Henrotay, BAMB Coordinator, Brussels Environment
Waste (building vacancy, refurbishment, etc.) is caused by design error. We need to retain building value, looking beyond immediate investment cost. We need a change in design and value culture, using an integrated approach that supports decision-making, taking into account all stakeholders and reversible design.

James Drinkwater, Director of World GBC's Europe Regional Network
Previous climate change debates in relation to the building sector have focused on energy usage in buildings, but we need to look at the built environment's embodied energy in order to decarbonize the building sector and move towards meeting the Paris Agreement goals. We need to develop a common language about circularity and complete life cycles to address and promote conversation with everyone in the industry; this can be achieved by providing robust and comparable data. This data should be provided through comprehensive circular building assessments, including environmental & economic evaluations, reversible building design, user information, BIM, material passports. Currently, there is a dilemma of balancing different objectives across sectors: how do we provide shared information in an easy, understandable form? Government and regulator policies are crucial for achieving circular economy; existing barriers must be removed.

Making the Right Decision for Circularity: Circular Building Assessment (CBA) Methodology & Prototype Platform
CBA overview: describes how a building is assembled and what it contains.
Components to consider in CBA: reversible building design (connections & level of reversibility or ease of disassembly), economic evaluation component, and social assessment. To assemble this information, need information exchange collaboration:

- *The hierarchy inherent in CBA must be connected to ISO standards (International Organization for Standardization).*
- *The properties must be available in BIM models and made available to designers, manufacturers, and clients at varying degrees of detail to help them make informed decisions (layers: project, building, spaces/rooms, elements, components/materials).*
- *It should be possible to run environmental and cost comparisons for building materials and components.*

At the design concept stage, architects need to be able to create basic LCA calculations to inform the design, which is difficult when many decisions (material) have not been made yet.

To inspire change, the market must request it. It is incumbent on clients and architects to ask the right questions, but circular solutions cannot be seen as a one-off approach: businesses need to see a viable future application.
With this tool, individual offices would need to build location-specific material data sets because LCA calculations are based on location. Digitization of these calculations and embedding them into standard practice will help promote a circular economy.

Mass Flow in Life Cycle of Buildings
by Thomas Lützkendorf
Buildings are able to contribute to a more sustainable development, but to convince people, we need a clearer universal language where science and practice are in a constant exchange. We need to close and slow down the materials cycle, and the existing building stock should be our starting point in looking for material sources for new buildings. A building's grave should not be the end of life of its components. In building LCA's, calculations are made for 50- & 100-year life cycles, but that is not reality; during the use stage, materials need to be maintained and replaced, causing a higher turnover. Other sectors can also use the existing building stock for secondary materials. We need to start with reusability, not recyclability.

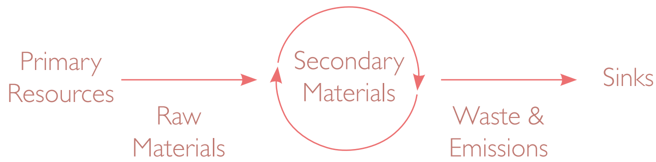
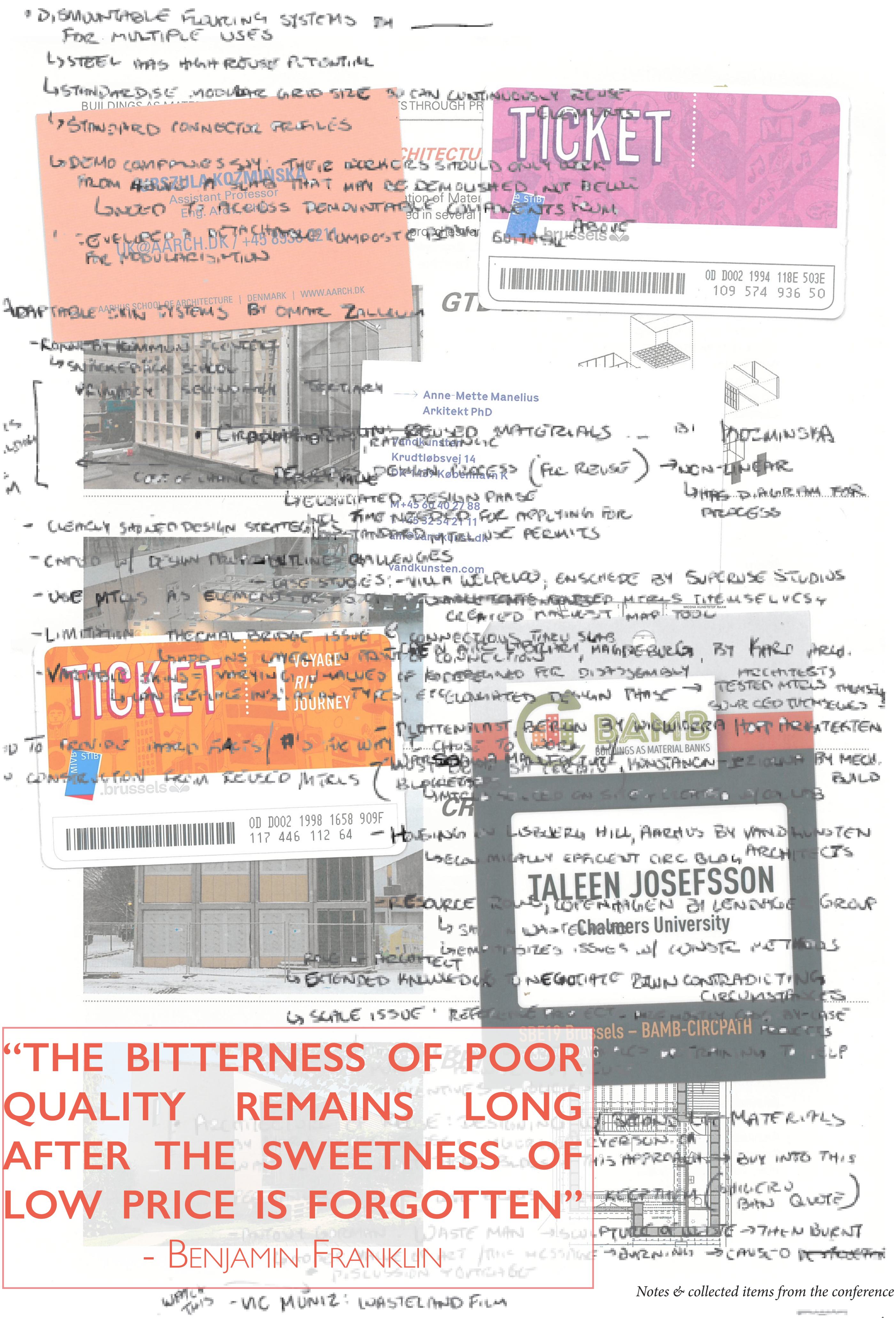


Diagram adapted from Lützkendorf's presentation

Waste and raw materials piled along the canal in Brussels



"THE BITTERNESS OF POOR QUALITY REMAINS LONG AFTER THE SWEETNESS OF LOW PRICE IS FORGOTTEN"

- Benjamin Franklin

Notes & collected items from the conference

Capture & Control of Material Flows & Stocks in Urban Residential Buildings
By Matthias A. Heinrich
Developed a model to quantify material flows and stocks of residential buildings (urban metabolism) which can match the supply and demand of materials.

A case study of Freiham, Germany produced data supporting the following:

Each building type and year / time period of construction results in a different material composition. Most existing data (prior to this study) is built on building shells and ignores building service materials. 50% of total existing building mass is contained in multi-residential buildings (age class 1958-68 (31%) & 1969-78 (19%)). The net worth of this mass is estimated at ±20 million euro.

As the population increases and brown fields are developed, material demand calculations will need to include green field sites as the demand for building sites increases. We need to know when materials will be available in order to balance the supply and demand. To meet this need, Heinrich calls for a centralized data platform and standardized material inventories.

"IN ADDITION TO THE CLASSIFICATION OF MATERIAL STOCKS (RAW MATERIAL CADASTRE FOR RESIDENTIAL BUILDINGS), IT IS OF CENTRAL INTEREST TO IDENTIFY FUTURE WASTE STREAMS IN ORDER TO FORECAST POTENTIAL SECONDARY RAW MATERIALS, DETERMINE RECOVERY STRATEGIES AND CONTROL MECHANISMS."

Capture and Control of Material Flows in Urban Residential Buildings: Case study Munich/ Freiham (Summary)
by Matthias A. Heinrich

It's All About Planning: Pre-Demolition Audits to Inform Public Calls for Tender for Enhanced Resource Management of Building Materials from Deconstruction
by Christina Ehlert, PhD
The national waste law in Luxembourg requires material inventories be taken as part of a demolition and material removal plan, but this is currently weakly implemented and controlled (the building owner is the source of the waste and is responsible for the inventory being properly executed). Ehlert proposes guidelines for best practices and standards for the material audits in Guide Pour L'Élaboration: de l'Inventaire des Matériaux de Construction Lors de la Déconstruction d'un Bâtiment (available only in French & German). The objectives of a pre-demolition audit and data collection are: regulation compliance, reduce cost and risk, minimize waste fractions, and enhance competence in material analysis and selective deconstruction. This study was conducted by a research team with complementary expertise: data collection, planning of structured dismantling for optimal execution, and contact with local companies / actors in the value chain. The goal is for Luxembourg to become self-sufficient in waste management (which it has not yet accomplished). In order to achieve this goal, there must be transparency and exchange of information (provide information from pre-demolition audit to bidders, bidders should submit waste management plan up front, & evaluate this as part of the award criteria), reporting and documentation of waste management, and a streamlined process (including comprehensive coordination efforts).

Lessons learned:

1. *Optimism in planning phase is important*
2. *Actors must network and share knowledge*
3. *Must develop methodology for deconstruction process*
4. *Strive for qualitative (not quantitative) targets.*

Further investigation is required to determine best practices for:

1. *Material inventory and management of high-grade vs. mixed materials*
2. *Reuse vs. qualitative recycling.*

The first step is to create these inventories (on individual project scale), then show the information on a larger geographical scale, and finally figure out what to do with these resources; we need to identify what type of recycling and reuse is possible.

Measuring Reuse Potential and Waste Creation of Wooden Facades
by Renata Androsevic
In order to reduce waste produced during a building's maintenance in the operation stage, the facade should be designed such that the envelope can be maintained without producing waste. All parts of the enclosure system should be removable without affecting the building's internal functions. In the design phase, a rating system should be used for component reuse potential and end of life options (to help designers and contractors make informed decisions) and a reversible building assessment a material streams analysis should be performed. Proper design of the intermediary of the wall component can extend the components life. The construction industry is currently trending towards easy installation rather than easy disassembly; this must be changed.

The Role of Resource Efficiency Towards Circular Economy
by Helena Gervasio
This study made use of LCA software and parametric calculations. Steel was found to have the highest possibility of reuse or recycling. Standard European buildings were used here as a benchmark to find buildings with a lower impact than the standard reference baseline impact, but they did not go so far as to propose best practices.

Materials Research to Achieve a Circular Economy in the Built Environment
by Luisa F. Cabeza
We have previously been very concerned about energy use during the operational life of a building, but this discounts the energy required for its material production, construction, and ultimate material disposal. When considering the embodied energy of a building, we must consider that there is no real end of life; buildings have a limited life, but the materials and components inside of them do not. The use of energy in a building's life cycle should calculate both the direct and indirect energy usage, including the evaluation of embodied energy, natural resources, etc. Material Flow Analysis can be used as a tool to account for the total material requirement in a building:

- *Domestic extraction of raw materials in nature: Lithosphere (abiotic & biotic materials), atmosphere (air), & hydrosphere (water)*
- *Ecological Rucksack (Hidden flows: earth, water, air)*

When choosing materials, we must adopt a holistic perspective to make an informed choice. The use of phase change materials is an example of needing to weigh the energy savings during operation against the energy required to produce and later dispose of the products. Phase change materials store energy well but are created from oil-based materials, which are energy intensive. Additionally, they must be encased in complex, composite assemblies, requiring a great deal of energy to separate and properly dispose of them. Ultimately, they have more embodied energy than is saved in operation energy.

Is it worth it to make certain material and component choices? We must use a holistic perspective when specifying materials, looking at emissions, energy, and all life stages. We need to question the status quo and the way things are done; do not blindly replicate sub-par solutions by those who came before. Use measuring tools (like LCA) to understand differences but must be consistent with how you measure and report data to avoid comparing apples to oranges.

The Reuse of Load-bearing Components
by Jan Brütting
40% of a building's embodied energy is sequestered in its structure. In this study, Brütting focused on:
1. *The reuse of components for the same purpose*
2. *The reuse of components for different purposes.*

Reference examples provided: Mesquite in Cordoba, Spain; 150m long wooden bridge in Freiburg, Switzerland built after WWII; London Olympic Stadium from 200,000 pipeline tubes.

In his pilot project design of a pavilion made of used skis, he reverse engineered the design; the design was born of the existing, limited constraints of the lengths of elements matched with existing technology for structural section optimization. He had used digital tools in combination with physical structural tests of used components to calculate the structural integrity of members for reuse. In another design (unbuilt), his team had proposed reusing steel structural members from old electrical towers in the new roof of Lausanne's train station by taking the members as they are and creating custom structural connections. In calculations, was constrained by existing stock, so oversized structural elements where required.

CONTINUED...
BAMB CONFERENCE (BUILDINGS AS MATERIAL BANKS) IN BRUSSELS, BELGIUM

Design of Composite Flooring Systems for Reuse
by M. Nijgh
Design philosophy:
Cast in situ → Prefab concrete elements
Welded studs → Demountable shear connectors
Single use → Remountable

Quantified the environmental benefits. Their proof of concept pilot project was a pre-fab car park. Determined that demountability and reusability of composite flooring systems is possible.

Dismountable Flooring Systems for Multiple Uses
by C. Odenbreit
Dismountable flooring systems using steel due to high reuse potential. This is most easily achieved by standardizing a modular grid size for future reuse; would also require standardized connector profiles.

Demolition companies require that their workers only work from above a slab that may be demolished, not below; demountable components must then be accessed from above. Developed a detachable composite beam suitable for modularization.

Adaptable Skin Systems
by Omar Zalloum (Chalmers, Msc Architecture)
Presented his master thesis research and design proposal. Worked with primary, secondary, and tertiary layers of the building system. One limitation was the thermal bridge issue at connections through the slab (in his proposal), requiring an added layer of insulation in front of proposed connections. Included a variable skin proposal where facade elements can be switched out, changing the U-value as desired (or just parts of the assemblies, such as the insulation without disturbing the entire facade).

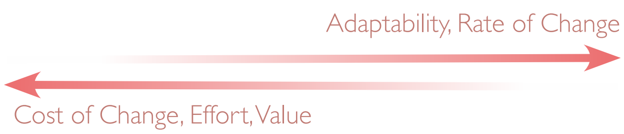


Diagram adapted from Zalloum's presentation

Circular Design: Reused Materials and the Future Reuse of Building Elements in Architecture. Processes, Challenges, & Case studies
by Urszula Kozminska, PhD
Describes the non-linear reuse design process and the differences between designing with used materials vs. designing for reuse. Both processes include interdisciplinary cooperation, an extended design phase, assessment of materials with specialist consultations, explicit project environmental goals, and a research portion. Designing with reused material includes time needed for applying for non-standard material use permits and iterative modifications of design and specifications throughout the entirety of the design and construction process. Designing for future reuse includes providing maintenance and future disassembly guidelines for users, as well as defining optimal future reuse applications.

Challenges:
- *Lack of data about material availability, amount, quality, and sourcing/ processing*
- *Lack of designer education in reuse*
- *No demand for reuse projects from general public*
- *Ineffective/ insufficient collection, separation, processing, and transport infrastructure*
- *Disassembly procedures*
- *Contamination of secondary resources*
- *Unknown properties of reused/ salvaged materials*
- *Difficulties in identifying material content*
- *Aesthetic properties*
- *Higher cost of construction/ perception of higher expense*
- *Lack of adequate business model framework*
- *Economic aspects: level of economic development, demand for reused materials, presence of incentives*
- *Existence of adequate spatial and pro-environmental policies*
- *Flexible and holistic approach to regulations and codes*
- *Urban planning (urban density, typology, function)*
- *Adequate building design*
- *Adequate choice of building materials (forms, dimensions, volume, age, technical properties, aesthetic condition, recycling potential)*
- *Amount of waste*
- *Frequency of renovation*
- *Lifespans of buildings*
- *Environmental impacts: energy, water consumption, pollution*
- *Impact on human health*
- *Social determinants: human customs, behaviors & habits, environmental awareness, social perception, authorities' awareness, social status and engagement*

Case Studies:
- Villa Welpeloo, Enschede by Superuse Studios
Architects sourced materials themselves and created Harvest Map tool (https://www.oogstkaart.nl)
- Open-Air Library, Magdeburg by KARO Architekten
Designed for disassembly. Included an elongated design phase. Architects tested & sourced the materials themselves.
- Plattenpalast, Berlin, by Wiewiorra Hopp Architekten
- Warsawa Manufacture, Konstancin-Jeziorna by Mech. Build
Reused materials sourced on site
- Housing on Lisbjerg Hill, Aarhus by Vandkunsten Architects
Economically efficient circular building

Resource Rows, Copenhagen by Lendager Group
Emphasizes construction method issues

Summary:

- *Role of Architect: extended knowledge to negotiate between contradicting circumstances in circular design process.*
- *Scale issue: reference projects are mostly one-off projects*
- *Architects need more examples or training to help move forward, in addition to incentives and supporting policies.*

Architecture of Reuse: Designing with Second Life Materials by Mark Gorgolewski
Want people to want buildings made from reused materials and to convince them to buy into the philosophy of continued material value.

The debate on material value and waste is not confined to the design and construction industry; it affects people worldwide:

- *Reuse in art: Antony Gormley's "Waste Man" sculpture created during the summer of 2006 in Margate, UK. This sculpture was built from waste collected from a local disposal center. The creation of art from the piles of waste gave it value. The subsequent burning of the sculpture sparked outrage and a discussion on the perception of value.*
- *"Waste Land," a documentary by artist Vik Muniz, documents the lives of urban waste miners in Brazil, including the collection of useful materials from garbage dumps for recycling and reuse. These miners rescue useful materials and give them value again, after disposal by their original owners.*

Examples of material reuse research, experimentation, and building include the following:

- *Nordic Built Component Reuse*
- *Small builder in USA - reuses material and adds damage to perfect bits so they match the old / worn elements.*
- *"Storywood" by Delta Wood (USA) - highlights individuality and character of old pieces of wood. How do we apply the story aspect to other materials?*
- *"A New Way of Seeing" by Aravena at the 2016 Venice Architecture Biennale employed waste materials from buildings in an installation meant to highlight the vast amounts available and the value/ beauty these materials still hold after they have been discarded.*
- *Posner Center by Tres Birds Workshop in Denver, Colorado. In this project, Tres Birds controlled the whole process and acted as the deconstructor, designer, contractor, and material supplier, allowing them to control the cost, quality, etc. Architecture as an ongoing process; how do we tap into this at different points of the process? This is an example of adaptive reuse with component reuse.*
- *Ford Calumet Environmental Center in Chicago, Illinois by Studio Gang is an example of reusing what is available. They harvested materials from a nearby building, as a bird collects materials from nearby for its nest. In this project, form followed availability. The structure was composed of a variety of steel components of varying sizes. The design took its cues from the available material.*

"FORM FOLLOWS AVAILABILITY"

- *Pocono Environmental Education Center in Pennsylvania by Bohlin Cywinski Jackson looked beyond what is available in the construction industry in material sourcing; the firm used other waste streams to source materials that can provide architectural value.*
- *Big Dig House in Boston, Massachusetts by John Hong was built in 2006 from materials reclaimed from the Big Dig, a major Boston highway construction project. This is a good example of reused materials forming a beautiful, modern aesthetic.*

"HOW DO WE CONVINCE SOCIETY TO ACCEPT IMPERFECTION?"

The architectural profession has lost touch with materials and construction techniques (and their residual values at different scales).

If we can show that there are cost benefits to this (reuse) approach, we can move the market in this direction.

Elma Durmisevic (University of Twente, Netherlands) has researched retail and restaurant examples where people want the "look" of worn materials, so they produce new materials and make them look old. Examples include:

- *Private domain: shops & restaurants*
- *Public domain: building exteriors - breaking barriers on exterior and entirety of building. Once it enters the public domain, it becomes a public discussion.*

"THE LOVEABILITY FACTOR"

(if people love it, they keep it)

The drivers needed for reuse to be possible:
Marketplace
Inspiration: architects will stimulate demand
Inspire inspirational architects to want to work with reuse
Cultural necessity of recognizing value of old materials
Need a broader platform for architects to access and share information.

"INSPIRE INSPIRATIONAL ARCHITECTS"

Architects have a responsibility: they are the interface between the sciences and clients. We need larger projects to motivate inspiration. Developers and investors will have to take on a certain amount of risk.

Architects often have ownership of design; this becomes a barrier in the reuse movement in that sharing designs is not encouraged. How do we scale up reuse approach in a beautiful way? One way to tackle this is through education: while much of architecture's beauty is dependent on the architect's talent, education can provide architects with tools to help them achieve a beautiful reuse architecture. Architectural education should increase its focus on working with existing buildings and reusing materials/ components rather than focusing on designing new construction.

To achieve reuse architecture at a larger scale, a combined approach is needed:

1. *Architects must take responsibility*
2. *Industry must support logistics for reused components*

We need a united market, instead of many small, individual marketplaces for reused materials and components to make material availability widespread and visible. We need to embrace imperfection; Get over needed all doors in a building to be identical (new) and instead design with what is available. Architects need to push embracing imperfection.

In North America, the sustainability agenda is centered around LEED or embodied energy and carbon, but it is missing the circular design discussion.

In the USA and Europe, there is an increasing trend of shrinking cities. The concepts of circularity and reuse could potentially be applied at these scales; this kind of thinking could be economically viable in bad economic areas such as these (ie. Detroit, where there are high unemployment rates and a lack of resources). In Kelgrade, Netherlands, an ongoing deconstruction/ gutting project for a 10-story housing block has been opened up to the neighbors for suggestions in how to reuse the material/ building. This is one example of social and technical circular thinking.

Economy of Architecture: architects have a huge responsibility over monetary investment yet architecture schools do not provide any economic training. What do we want from architects? No one agrees on what architects should be delivering. What will be expected of architects in the future?

Agility in Architectural Design Towards Regenerative Cities by Steven Beckers

If want to look beyond sustainability, start with a vision, not a numerical goal. Beckers works with renovation with regenerative and positive impact circular economy thinking:

- *Healthy & inspiring*
- *Added value for society*
- *Building as raw material bank*
- *Flexible and convertible*

Society needs to improve resource circularity within:

- *Technological material*
- *Biological material*
- *Energy*
- *Water*
- *Carbon (Beckers does not believe in carbon neutrality, rather in carbon positivity, where carbon is reused as a material, like in photosynthesis)*

Reference Projects / Companies working with circularity:

- *Office for Tourisme du Gard by JF Daures Architecte was designed and built for biodegredation*
- *McDonough & Partners (USA) designed a concrete building for disassembly and designed with techno and bio cycles.*
- *Smart Crushing (Netherlands) is a company that recuperates sand, stone aggregate, and unactivated cement from concrete (20-30% of cement is not activated in concrete mixtures) and reuse the concrete on site.*
- *Citizen M hotel in London is an agile construction mixed system. It is prefab, built for disassembly, and designed with spatial generosity to avoid obsolescence. The issues with this project/ prefab construction is that when requesting a construction loan, the bank visits the site to monitor the progress and determine that the money is being used correctly and on schedule; if a problem occurs, the bank reclaims the materials. However, prefab moves very quickly and does not follow a typical construction schedule (on site). Without the ability to monitor progress on site, in addition to the ability for anyone to drive the materials away at any time prior to assembly, the old construction loan system does not work.*
- *Beckers is involved with an ongoing project where transforming suburban car park and big box store typology (ugly, polluting, etc.) over time into functional buildings using a modular concept. Incremental foundation drilling in the existing car park will provide a system for fast future transformation.*
- *Maison du Projet in Roubaix, France by Carlos Arroyo & EKOA Architects designed a good compromise where they built for the best re-use possibilities with upcycled materials, using a steel foundation with timber structure.*

Architects should make buildings productive:

- *Use CO_2 as a raw material*
- *Produce energy & clean water*
- *Produce biodiversity & hums*
- *Produce healthy materials*
- *Produce food*

Architects need to break traditional city planning rules to design and build productive cities.

How to Design Buildings with Life Cycle Assessment by Rodrigo Castro

The goal of circular economy is to preserve material value in the economy and reduce material extraction.
LCA's must be calculated within the project context.

When assessing material choices, consider:

- *Service life*
- *Embodied carbon*
- *End of life scenario (expected)*

Castro built a model calculating the embodied carbon in each building element. He determined that there is high variability in LCA values in internal renovations (with new, raw materials). For interior renovations, the model shows a carbon footprint in the B-phase of the LCA to be as large as the footprint of the initial building construction (A-phase).

Architects must design for change (service life) & resource efficiency.

Rebeauty: Artistic Strategies for Repurposing Material Components by Anne-Mette Manelius (Vandkunsten)

Manelius presented Vandkunsten's Nordic Built Component Reuse report (2017), in which the firm tested new applications for salvaged building materials.
Project aims:

1. *Repurpose building waste from demolishing, dismantling, and refurbishing*
2. *Reversible construction principles (Design for Disassembly)*

Without beauty, there will be no sustainability.

To identify possible component reuse scenarios, Vandkunsten mapped components in a "Rebeauty matrix" by combining 2 existing classification systems: SfB (Samarbetskommittén för Byggnadsfrågor, a numbered Swedish system for classifying materials) and Steven Brand's Layers Diagram (Brand, 1994). Based on this matrix, they created 19 material reuse prototypes for which they created cultural, economic assessments, and LCA's based on flow diagrams to determine the most successful experiments.

Five initiatives: promoting a higher degree of component reuse:

1. *Upcycling industry*
2. *Education*
3. *Design for deconstruction*
4. *Local distribution*
5. *Waste management*

City as a Material Bank: Constructing with Reuse in Musicon, Roskilde by Anne-Mette Manelius
Musicon is an urban mixed-use brownfield development at a former concrete plant, consisting of a non-linear development of design at multiple scales in the area. The project by Vandkunsten is in the building named Hal 7, which is a former industrial hall. The project has a 10-year lease and serves 3 municipal groups and whose functions must benefit all 3 groups.

The design for Hal 7 was partially inspired by Vandkunsten's earlier Copenhagen Village project, in which they used shipping containers to create housing in the city. They tested design for disassembly techniques and different ways of insulating the buildings. One conclusion was that it is very expensive to insulate shipping containers from the inside and less expensive to insulate them from the outside.

Hal 7 is divided into multiple noise and heating zones. Shipping containers are placed within the hall to create spaces for and divide the different functions. The container interiors are insulated and heated to 21ºC (and can be moved to another location once the lease ends).

The final design of Hal 7 is based on material availability. The project consists of ±90% reused materials, including the original building, which remains.

See the summary of the study visit to Vandkunsten for more on this project

A New Evaluation Method for the End-of-Life Phase of Buildings by Hildegund Figl

How should material the composition of buildings be designed so it leaves as many recyclables as possible and as little problematic waste as possible at the building's end of life?
Conditions for the evaluation tool:

- *Based on building elements approach.*
- *Integral in existing LCA tool*

Qualitative assessment: the quality of potential future life of materials as a consequence of previous steps (graded material output)
Goal: merged end of life tool with material database from LCA tool.

Demolition vs Transformation: "Mortality of building structures" depending on their technical building properties by Rijk Block & Patrik Teuffel
What is influential in the technological properties of a building? Does flexibility pay? It requires more materials, causing one to be punished for an increased footprint.

This paper evaluated the relationship between building layers to determine length of a building's life:

- *Scored layers according to 64 parameters to find out what is the most influential. Parameters included demountability, space plans, etc.*
- *Compared demolished and renovated buildings of 3 floors or higher and tried to find correlations between them*

Certain parameters were more important in determining building life than others. Transformed buildings had an average service life of ±60 years only. The scores established through this technique were a reliable indicator for whether a building would be demolished or transformed, as well as its life length.

Conclusion: for a longer building life, sufficient space for change and access to horizontal spaces is required.

Circular Construction for a Post-Fossil Fuel Society by M. Crabbe
This lecture described the process and findings for a design-build project (Infozentrale auf dem Vollgut) by students at the Natural Building Lab in Berlin. The project employed circular construction solutions using salvaged and waste materials.

The students began by identifying material and waste sources in the urban Berlin area. One material used was recovered timber from a temporary pavilion by Raumlabor Architects. The timber sections they recovered were smaller than required for the structure, so they built a lattice structure where they were able to integrate small sections instead of large, solid beams. The students also built composite columns, which were bolted together and could be dismantled at a later date.

Developed interesting circular window details. Since they collected many elements of varying sizes, they had to solve details and joinery on site. This can become a scale issue in larger projects.

Issue of building codes: thermal performance and fire safety. This was a temporary pavilion, so did not need to take these constraints into account as one normally would.

The group built a wide network of collaboration (https://nbl.berlin/BUILDinG-CYCLE)

BAMB Conference Summary & Reflections:

The conference was a great introduction to ongoing research and projects in academia, architectural practice, and the construction industry. There was so much information to process (and it was impossible to attend all of the lectures) that only some of the proceedings are recorded here. Access to the conference papers and presentations is available at: https://www.bamb2020.eu/final-event/research-days/

The presenters provided valuable background for this thesis' research in addition to highlighting the many challenges involved in building material and component reuse. Some provided construction and joinery solutions, but the general feeling is that a lot more experimentation and demand is required for material reuse to become widely practiced and to establish tried and true methods. Without a plethora of successful projects to draw inspiration from, it is difficult for other architects to employ such solutions in their work.

Additionally, the conference placed a great deal of emphasis on the need for education and access to and transparency of information in order to move circular thinking and material reuse forward. It is imperative to share the progress made and build upon colleagues' work to achieve the collective vision of a circular future.

ANLEITUNG ZUM ERSTELLEN DES INVENTARS VON BAUMATERIALIEN BEIM GEBÄUDERÜCKBAU BY LE GOUVERNEMENT DU GRAND-DUCHÉ DE LUXEMBOURG, MINISTÈRE DU DÉVELOPPEMENT DURABLE ET DES INFRASTRUCTURES, ADMINISTRATION DE L'ENVIRONNEMENT

"Instructions for Creating the Inventory of Building Materials in Building Demolition"
(Translated by Jan Dankmeyer)
As presented by Christina Ehlert, PHD at BAMB Feb 2019

Translated excerpts:
Building & demolition waste is 25-30% of waste volume in EU and is therefore the largest volume in the waste flow.
Modified law 21 March 2012 - enhance reuse and recycling of building and demolition waste; accumulation and division of waste types should be as clean as possible. If not possible on the demolition site, it's important to do so off-site.
Article 27 - in the case of building demolition, a building material inventory list must be taken and submitted to the city's environmental department. It is supposed to be an instrument for planning and resource management. The material inventory is supposed to guide stakeholders in acting accordingly to the waste regulations.

Responsibilities:
In the case of demolition, the property owner / building owner is responsible for the planning and establishment of the material inventory list. There are a variety of phases to establish the list; it requires a high level of expertise and thereby the client is obliged to procure experts to conduct the material survey. Since the material list is project-dependent and varies from project to project, it should be introduced as soon as possible between the client and the demolition company.

Cost and resource efficient demolition:
When building materials are mixed after demolition, it is costly and time-consuming to transform them back into clean, reusable materials (and maintain their value). Separating the accumulation of materials prior to demolition can lead to clean separated materials streams and is recommended. With a clear separation of the waste, it is easier to promote recycling and reuse. Selective demolition supports high quality recycling. Furthermore, the identification of contaminated building materials is necessary to prevent the dangerous waste from re-entering the usable material stream. This is to be disposed of according to local regulations.

General Action Recommendations:
The material should be divided as cleanly as possible to guarantee high quality recycling. If necessary, provide secure packaging. The personnel on the demolition site must be informed of the division. The containers for accumulated material must be labeled accordingly.

Hierarchy regarding demolition & reuse:
1. *Prevent waste - client should think about if they want to reuse building elements or complete structures*
2. *Recycling - treat / process waste & materials to be able to reuse them*
3. *Exploitation - new materials are substituted by waste or by treated waste (recycled)*
4. *Disposal - sometimes it is necessary to treat the waste prior to disposal to guarantee that it is free from hazardous contamination*

Making an Inventory:
1. *Thoroughly plan the demolition, renovation, and rebuilding with reused / recycled materials to reach maximum efficiency and minimize the effect on the environment. The main target is the identification and assessment of the material quantity. Start as early as possible in the process to reach a high level of reuse and recycling and to strengthen the potential of minimizing costs.*
2. *Examination of the planning of inventory:*
3. *Assess and evaluate the existing information (for example existing site plans, drawings, heights, and reports regarding contamination testing).*
4. *On-site visit to evaluate contamination.*
5. *Estimate the amount and assess the materials.*
6. *Evaluate quality of the material to be able to determine which materials can be reused or recycled and which must be disposed of.*

Guidelines:
1. *Description of the building and its function: It is necessary to gather all information, such as the year of construction, renovations & their purposes to be able to plan the demolition. This information is used for the evaluation of potential contamination. Information regarding the functions of renovations and of the building can provide further insight regarding potential contamination to be expected (or not).*
2. *In case of renovation of a fire-damaged building, you need a special evaluation to assess the extent of the damages resulting from the fire.*

When doing a survey of contamination, meet the following goals:
1. *Establish the level of pollution: identify poisonous and dangerous waste*
2. *Planning of the necessary division and demolition techniques*
3. *Set up the disposal and exploitation techniques / logistics.*
4. *This examination is an important base for the evaluation of the degree of reuse, as well as the planning, cost calculation, and the various phases of the demolition process.*

PILOT PROJECTS
BAMB CONFERENCE (BUILDINGS AS MATERIAL BANKS) IN BRUSSELS, BELGIUM

2 Exterior wall modules & steel foundation pillar (on floor)

Column prototype

BRIC (Buildng Reversible in Conception), Brussels
Collab: students & Karbon' Architecture et Urbanisme

Objective of pilot project was to design a building that could be rebuilt 3 times with 100% reuse of the first version's components. To optimize reuse, modeled the building and all of its components in BIM and a physical scale model to understand component sizes and connections. Each component received a bar code with its material passport. When disassemble and reassemble, must use high quality materials to avoid them falling apart during the process.

- *Foundation: steel pillars screwed into ground.*
- *Columns: composed of 4 wood components: employed massive wood instead of Glulam or CLT. These carried the floor loads.*
- *Exterior walls: plywood boxes later filled with insulation; carried load of exterior walls only. 22mm OSB placed on exterior for air sealing.*
- *Insulation: Cellulose insulation which could be vacuumed out during disassembly and refilled later; had to purchase new from the start because didn't know the chemical composition of reclaimed.*

Circular Retrofit Lab under construction (February 2019)

Interior wall assembly product by Saint-Gobain

CRL (Circular Retrofit Lab), Brussels
by Vrije Universiteit Brussel (VUB)

This project reused 8 existing prefab concrete housing modules from the VUB campus, originally designed as temporary student housing by Willy Van Der Meeren in 1973, as a structural base for the experimental building. The design is intended to be transformable with demountable and reusable interior and exterior wall kits and openings; initial design planning has anticipated rearrangement in 12 different scenarios.

Planning for the future was a crucial part of the design: not only do the interior partitions and finishes need to be removable and transformable for multiple layouts and maintenance but building services (non-integrated) had to meet the needs of future programs and higher demands ranging from housing to a restaurant.

Experimentation with wall systems employed both kits currently on the market but applied in new ways as well as new assemblies about to hit the market.
Lessons learned:

1. *Many circular products exist on the market, but architects can rethink their applications.*
2. *Find incentives for partners to produce circular products through an ability to replicate, certification opportunities, and scalable solutions.*

Detail of CRL interior partition using Gerberit's in-wall toilet tank system

CRL interior partition using Gerberit's in-wall toilet tank system

CRL exterior wall

REMS (Reversible Experience Modules), Netherlands by EPEA

This was a traveling exhibition that showcased circular building and products with material passports, which was displayed 6 times throughout Europe. Its repetitive 2mx1m grid was composed of an aluminum structure that took an interior contractor team 2 days to assemble or disassemble. Both processes required care so as to maintain integrity of the components; when disassembling, each piece was packed in its custom-designed traveling box. Each component was labeled with a QR code linking it to its material passport, accessible by mobile phone. Material passport standards must be established with minimum requirements to guarante quality.

Lessons learned:

1. *Material passport interface should be aesthetically attractive and comprehensible.*
2. *Visual summaries are valued by producers so can communicate main points to clients. Providing producers with communication tools is an incentive for them to fill out the passports.*
3. *Adaptability & reversibility limit time & function. This assembly was not indefinitely adaptable due to wear on the aluminum frames.*

Reversible GTB Lab Module, Netherlands by ODS

The module represents a new business model by Kloeckner metals ODS facade community (building owner, investor). It uses steel products at the end of their first lives for new modules.

Module objectives:

1. *Reversibility on module level*
2. *Reversibility on component level*
3. *Design production measurement coordination*
4. *Extendability*

The steel in the module was combined with wooden cassettes produced with CNC milling techniques for connection precision.

Glass panels were mounted on the exterior that functioned as space heating and photovoltaic production with a 0.8 U-value and high translucency properties.

IDA TOLL OF NUDIE JEANS IN GÖTEBORG, SWEDEN

Ida is the in-house architect for Nudie, a Göteborg-based jeans company that began in 2001 and has maintained a strong focus on sustainability in every aspect of their company. She works mostly with interiors and has designed all 31 of their boutiques located in Europe, North America, Asia, and Australia.

Nudie's commitment to environmental and social sustainability is a corporate decision; they are trying to work with consumption in a sustainable way. Their product is 100% organic, they provide jeans repair and a buy-back program, have an online secondhand jeans market, and finally try to minimize their environmental impact in the design and material sourcing for their brick and mortar locations. Ida sources interior design (both fixed interiors and movable furnishings) as locally as possible combining mainly natural materials with as few components as possible (to allow for better disassembly and reuse in the future), reused components and furnishings, and products made from recycled or post-consumer materials. She consults the Sundahus database as a materials reference when searching for new products, but also uses Nudie's far-reaching wholesale vintage sourcing network to procure used items for their boutiques. Pamono.se is one such source where Ida can request items (such as shelving with certain measurements) and have a company representative match available items with her needs.

One issue with the reuse and local material procurement process is that each individual location is unique and the design and sourcing process takes a great deal of time. A sustainable product in Sweden is no longer a sustainable choice in Australia due to the carbon emissions needed for transport and sometimes even different wood fumigation requirements. They experiment with using different products and applying them in new ways, trying to make the choices with the least environmental and health impact. Working with interiors allows her to try one-off small-scale solutions, in contrast to the larger-scale solutions required in a building, which must function in a more systemic manner.

Ida also subscribes to the concept that the most environmentally friendly boutique design is one that requires no change to the building at all. Rather than install new flooring or wall coverings, they would rather keep the existing if possible. This allows for the history and character of the building to be maintained to create an interesting interior for the Nudie boutique as well as to preserve the character for future building tenants.

Nudie's boutique interiors receive a great deal of wear and have a lifespan of about 3 years. Small renovations occur to fix broken interiors but do not have a seasonal turnover as seen in larger box stores, such as H&M, where interior design turnover is nearly as high as their 52 clothing season changes each year.

At the moment, Ida is focusing her design on the storytelling aspect: sourcing materials that show their history, such as recycled plastic paneling with marbling. She is also designing monolithic expressions of wood paneling, assembled mainly with wooden plugs and glue (Carb2 certified, without formaldehyde). She works closely with craftsmen whose quality she can trust to find solutions for on-site construction and updating reused materials to meet the store's needs.

Recommended the following brands:

- *Kvadrat (https://kvadrat.dk)*
- *Really panels with cellulose-based glue*
- *Ecobirdy (https://www.ecobirdy.com)*
- *Econyl (https://www.econyl.com/interiors/)*
- *Pamono (https://www.pamono.se)*
- *Auro interior paint (https://www.auro.de/en/)*

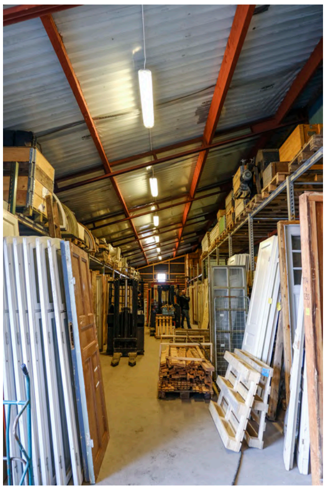
Nudie Jeans HQ office where old bank building meets new needs

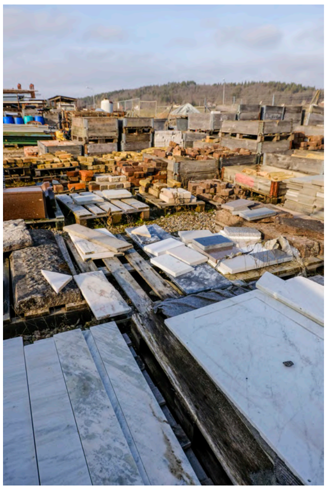
HUS TILL HUS IN ALINGSÅS, SWEDEN

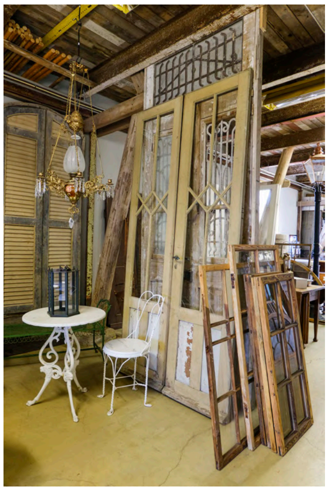
Hus Till Hus is the largest (and one of the only) secondhand building materials warehouses / retailers in Västra Götaland. Located on a spacious farm plot in Alingsås, materials are stored in heated indoor and unheated, covered structures, as well as a large outdoor yard open to the elements.

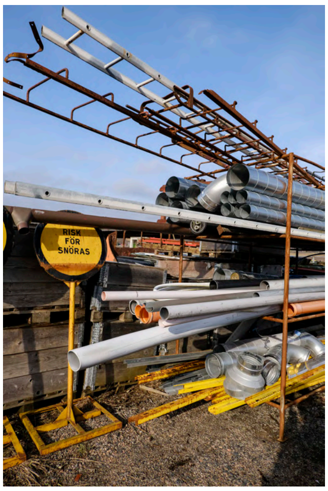
Used materials available from Hus till Hus include timber beams, windows, doors, interior and exterior hardware, roof tiles, pipes and ducts, and fireplaces. Not only is this material available in their brick and mortar location but also advertised and sold on blocket.se (a Swedish version of Craigslist.com), an online platform where users sell their own items and services.

While the items stored in sheltered areas were in excellent or very good shape, a great deal of the materials and components stored outdoors in an uncovered setting where in poor, semi-usable shape or in need of intense rehabilitation if to be reused. It seemed that more facilities were needed to house and exhibit the materials available, indicating that there is a large amount of used building material in the area but the organization does not have the capacity to care for or store such large quantities.









ANNE-METTE MANELIUS, KATRINE WEST KRISTENSEN, SALMA ZAVARI, & JAN SCHIPULL KAUSCHEN OF VANDKUNSTEN ARCHITECTS IN COPENHAGEN, DENMARK

Vandkunsten Architects' office

BARRIERS

In the reuse of building materials, the logistics portion is missing.

In order for a project with material reuse to happen, there needs to be a shared vision for and commitment to environmental protection. There is currently no economic argument for reuse given the lack of tested methods and logistics framework.

Both clients and contractors must be convinced to specify reused materials in construction with good cause; materials sourced or found secondhand pose a much greater risk than those coming directly from a manufacturer holding a material guarantee (ie. 25 year roofing material guarantee). Should part or all of the material fail, there is no clear entity responsible for replacing it or fixing damage resulting from the defect; there could be a question of material failure or installation failure, in which both would be difficult to hold the contractor responsible given that secondhand material does not come with specific installation instructions. This poses an economic risk for the owner.

TESTING & QUALITY CONTROL

Found and collected secondhand materials must be tested for chemical content (if it will impact the indoor environment) and structural integrity (as required). This can be an uncertain, lengthy, and expensive process because the client may need to spend a great deal of money to send the material to a lab and wait months for a result (in this case we discussing concrete stocks obtained by a demolition contractor and sent to the Netherlands for testing). If the material turns out to be unusable, this could be a waste of time and money, sending the team back to the drawing board.

Testing of materials or components may need to occur on site if transporting the material is not an option. This runs the risk of ruining the material (should it fail). When structural integrity is an issue, the default choice is to over-dimension the structural elements rather than run the risk of faulty components of the correct size. This could potentially be a wasteful use of material. Knowing a material's history and make-up (such as through a materials passport) would be beneficial to minimize uncertainty and help prevent unnecessary time and money spent on the testing process.

EXPERIMENTATION

One way to test building methods and techniques, as well as gain support for the practice of material reuse from the community, municipality, and regulators is to design temporary public structures (i.e. Vandkunsten's Hal7 project in Musicon, a development district in Roskilde). These could not only be designed with reuse as a primary material design strategy but also designed for disassembly given their temporary nature. With the short lifetime of the building, economic investment must be proportional. At the end of the building's lifetime, it would be deconstructed / disassembled and the designers and contractors would learn from these experiences which methods worked or failed in both the construction and deconstruction phases.

The municipality could start the reuse movement; the municipality records which sites and buildings will be demolished or are in transitional periods, which could benefit from these temporary interventions. Additionally, *municipalities often have ample storage facilities in which the used material could be collected and stored prior to construction. In sponsoring temporary pilot projects, the possibility to test techniques and the establishment of a framework for logistics could incite interest in and build the basis for a reuse economy.*

In Denmark, when a structure is designated as temporary from the outset, dispensation of many building issues and regulations are allowed. Fire safety is, of course, nonnegotiable, but in the case of Hal7, the department of building allowed certain measures that apply to "permanent" structures to be forgone, giving Vandkunsten and the contractor the freedom to experiment a bit more than would otherwise be possible. Material and assembly testing could also be done in buildings such as waste sheds, where heating and other demands are not required, but one could still mount a new facade assembly prototype for weathering, durability, and moisture protection studies.

During the temporary building's life, it would (hopefully) become loved by the community and integrated into the fabric of the city or town; attachment to the building and its programs would boost support for such works, contributing to the city's identity and sense of place.

By determining successful building methods and techniques in addition to garnering widespread support and demand for reuse, building regulations which prevent or complicate material reuse today could be lifted, allowing the practice to be more widespread.

INVENTORIES & DECONSTRUCTION

Material inventory and deconstruction / demounting must be done by experienced professionals. In the case of Hal7, the city called in architects from Vandkunsten to perform a material inventory, from which they determined what could be salvaged directly from the existing warehouse building, the amounts and sizes of materials, and the work needed for proper disassembly. The contractor on this job signed on with a pre-established interest and training in material salvaging and reuse, so no special training in careful deconstruction of buildings was required; the contractor knew which materials were valuable and able to be resold later, as well as how to maintain the value. This contractor was later asked to train and consult another construction firm working with a second reuse project by Vandkunsten, as the second firm did not have sufficient disassembly knowledge.

Vandkunsten's flexible interior partition prototype created from used wood & particle board

CONTINUED...
VANDKUNSTEN ARCHITECTS IN COPENHAGEN, DENMARK

DESIGN PHASE

The design phase of a reuse project is not as black and white in conception to design completion as a typical project with raw materials. The architect must begin with a strong design concept that can be continuously refined throughout the process as usable building components are found and collected. This has an impact on the amount of time the architect allocates to the analysis/ pre-design, design, and construction phases respectively; Vandkunsten recommended that the greatest amount of time be spent on the design refinement and problem-solving during the construction process.

Once the initial design concept was determined, the architect placed all existing and found construction elements in a 3D model from which they continuously adjusted the design.

For this kind of project, where the construction components were finalized during construction rather than known during the design period, one should design a modular structural frame system (with standard measurements: increments of 60cm were used, the Danish standard), so that the contractor can fit strange reused components into the frames. One solution for this is off-site prefab structural components. In specificying standard measurements for the components, the demolition company can collect used materials that fit those parameters and cut them down to the standard sizes during selective deconstruction.

LCA & BUILDING LAYERS

In Denmark, buildings located in the city have the shortest lifespans of buildings regionally. This is due to economic and development reasons rather than the rate of wear and tear, which is actually much higher for buildings in the countryside, exposed to higher wind loads and other environmental factors.

When considering a the lifespans of building layers and how to properly evaluate these in life cycle analysis calculations, you should approach this by considering the kind of market in which the building will be built in and its location, in addition to the material's standard lifetime, as is typically done in LCA's.

It is difficult to calculate LCA's with reused materials at this moment; there is no good method to do so because there are too many parameters and no clear system boundaries. In an LCA with reused materials, it is not correct to input the material's embodied energy as 0 $kgCO_2$ in Phase A; the embodied energy input should be derived from what would have been the original Phase A value with adjusted to the actual time of previous use in relation to expected future lifetime.

CULTURAL & HISTORICAL CONNECTIONS

Building component reuse is not a new concept. Examples include the "spolia" of ancient Rome and the columns of the Mezquita de Córdoba in Spain.

The cultural values related to reused materials are high; recognizable building components that were previously part of the city's built identity can be incorporated into new structures, forming an interesting narrative and linking the new building to a place's history. It is important to incorporate the reused materials in a beautiful way; humans are attracted to beauty.

The story (of a material or component) increases the cultural value and even increases the lifetime of the building. When people develop a connection to their built environment, they want to protect it, in essence extending a building's lifetime, increasing its sustainability. The first role of sustainability is to build something that no one will want to tear down.

How do you quantify the non-qualitative elements of architecture (i.e. benefits of beauty, story, etc.)? These qualities be marketed can make a building more attractive and can ultimately translate into economic benefit.

OTHER CONSIDERATIONS

If Denmark reuses more materials, there will be a lack of fuel for the incinerators that provide energy to the country; as it is, Denmark is importing garbage. The larger effects of changing the system should be evaluated.

We must weigh the pros and cons of our material choices:

- *EPS, despite being plastic, can easily be reused. Untreated wood would seem to have a shorter life than treated wood, but this is untrue; untreated wood costs less and requires less maintenance. Painting or treating wood reduces its future reuse potential.*
- *Producing and specifying thicker wood planks than today's standard would greatly increase the material's lifetime.*
- *Structural protection: big roof overhangs can be used to protect the facade and thus the lifespan of the facade material.*
- *Windows with exposed aluminum frames can easily be disassembled and the aluminum can live on, either recycled or with direct component reuse.*
- *Industrial vs. human physical labor in regards to a building or material's embodied energy: use of machinery may be cheaper but requires a higher energy input.*

EXAMPLES OF VANDKUNSTEN'S FACADE PROTOTYPES CREATED FROM USED MATERIALS

Folded sheet metal facade 1 with paint

Folded sheet metal facade 2

Flattened air ducts hung on wooden structure with roof tile clips

Metal roof gutters applied vertically on a wooden structure

PETTER REUTERHOLT OF MATERIAL CONNEXION IN SKÖVDE, SWEDEN

I visited Material ConneXion to look for innovative uses of materials that are not widely available or found at mainstream material suppliers.

While the material library has a wide range of materials from natural to high tech, I was specifically interested in materials containing reclaimed, waste, industrial by-products, or post-consumer materials for construction purposes. I found potential structure, insulation, facade, and interior surface materials created from waste; however, most of the samples available made me question if they actually made the best use of their original materials.

On one hand, many of the samples used epoxy resins to bind together crushed aggregate, which I want to avoid given the dangers of off-gassing and chemical contamination of the interior environment affecting user health.

On the other hand, is it really adding value to a material (or upcycling) to grind it up, mix it with other ground materials, and immobilize it in a concrete-based or resin binding agent from which it could never be recovered?

I discussed the above with Petter; while he agreed that we should question if immobilization of materials with a new useful application is not the best choice, it also depends on how the original material was found. If we need to recover material from existing waste piles and streams, it may be difficult to sort them correctly, and grinding for use as aggregate in bricks or boards may be the most efficient way to handle the waste. In the larger scheme of things, the best waste management method would be to avoid discarding or sending the material into the waste stream at all. The owner of the material should prevent it from becoming waste as the first choice, find a new use without processing as a second choice, or send it to be properly dismantled and recycled as a third choice.

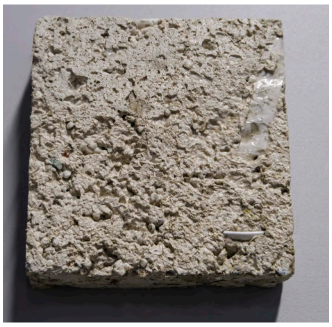
To quote Petter, it is better to use materials that manage the waste imperfectly than to continue as we are, waiting for the perfect solution to come along.

The materials library in Skövde, Sweden
March 2019

Yoghurt / Charcoal
by Smile Plastics, Inc.
Solid surface panels made from post-consumer and post-industrial yoghurt containers. Can be used for walls, ceilings, countertops, & flooring.

WasteBasedBricks
by Stonecycling
Cement-based
Brick made form construction waste from within a 150km radius (Glass, bricks, concrete, porcelain, etc.). The material is ground into a find aggregate and baked at high temperatures to create this brick.

Carbicrete Concrete Masonry Unit
by Carbicrete
A carbon-negative concrete product. It can be used structurally.

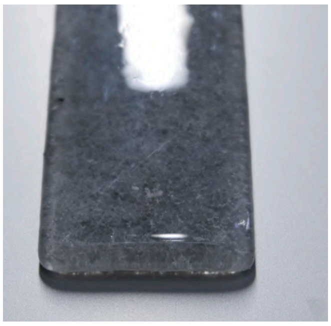


Re>Crete>
by Charles Goldman
Cement-based
A concrete panel with aggregate from ground up household waste. Lightweight & sound insulating. Available in modules maximum 15cm thick.

Eco-A.R.T.
by Hytex Industries, Inc.
Acoustic wall covering made from 100% recycled PET bottles with a noise reduction coefficient of up to 0.25.

Bottle
by Smile Plastics, Inc.
Rigid decorative panels made from post-consumer and post-industrial PET bottles. Can be used for work surfaces, table tops, bathroom paneling, doors, shelving, indoor & outdoor furniture.

ReWall Naked Board
by The ReWall Company, LLC
Polyethylene coated beverage cartons, cups, & other paper products. Can be used as a decorative interior wall finish.



CRT Glass Tile
by FireClay Tile Inc.
Glass tiles from 100% post-consumer cathode ray tubes, which were used in tv and computer monitors from 1907- early 2000's prior to the introduction of LED screens.

Tuf-Felt
by Sutherland Felt Company
Felt textile made from recycled pre-consumer fiber. Contains no chemical binders or retardants. Can be used for insulation, underlayment, and absorbent floor matting.

Net Effect One & Two
by Interface United States HQ
Modular carpets made of discarded fishing nets found in the ocean.

CHRISTER OWE OF ORUST KRETSLOPPSAKADEMIN IN GÖTEBORG, SWEDEN

Mollösund, Orust
July 2014

Consider the environmental implications of transportation; when working in Orust, the organization is trying to develop a local closed loop economy. Christer cited "the last mile," which he described as transitioning from long distance traffic to local traffic for the boundary of acceptable transportation; he considers wagons pulled by electric bikes to be the goal for local transportation as the best option in terms of low-energy usage.

We need to find another word "waste" when discussing material that still has value.

We need to find feasible economic solutions in the circular material economy to make it possible to do. At the moment, the problem is finding someone to pay for careful deconstruction of buildings and handling prior to selling it.

The standardization of building element dimensions is needed to scale up the practice of reuse in the building industry. Designers and contractors must know that certain elements are in available and salable in order for this to be a feasible building method.

Orust Kretsloppsakademin is working on multiple fronts with the question of sustainability, including creating programs for the sustainable handling of textiles, bicycles, and building. They will be opening a brick-and-mortar location at Vrälands Gammla Mejeri on Orust, which will be used as an office, workshop, and training center. This will not only be used as a workshop for production and repair (local job creation) but also as a teaching and training center for locals to learn about sustainable practices and repairing techniques, ultimately supporting local social sustainability.

The building is a 3-story warehouse / storage building that requires some transformation. The space will be rented from a private entity.

The organization has received support from the municipality but no money. This is good in that they are not tied to the municipality's political decisions and budget restrictions.

FLORIJN DE GRAAF (SKYPE INTERVIEW)

Florijn is an engineer working with smart, integrated decentralized energy systems. Through involvement as both a master thesis student and working for Metabolic (Amsterdam), he has was involved with the energy design of Ardehuizen, a 23-house earthship eco-village (Ahmed, 2018).

Questions for Florijn:

- *To meet household energy production goals, will there be enough heavy metals to produce enough PV panels & batteries at a fast enough rate?*
- *Which alternatives to PVs are the best options?*
- *The lifespans of PV's and batteries have a specific time frame in which they are most effective. When their useful life has ended, how do you dispose of them and can they be recycled?*
- *Was any of the energy system grid created from reused material or found?*

There is a trend toward decentralization of renewable energy both in existing and upcoming developments in Amsterdam in which one may sell energy produced on one's own property directly to his or her neighbors. In 2018 the EU passed a bill (the Clean Energy for All Europeans package) that allows people to start local energy communities where people can buy and sell on the local wholesale market. This is new and interesting because people can be their own operator and it allows for the democratization of energy.

The Ardehuizen neighborhood:

The project was made possible by a collective financing and construction of the houses (80% by the owners, 20% by professionals).

Earthship construction:

Limestone was used for plastering the exterior and interior walls. Recycled car tires were used for load-bearing walls, while the rest consisted of wooden frame construction with straw bale insulation.

Passive solar strategy:

Sandcrete flooring (20cm thick) was installed on top of concrete floor slabs (20cm) with the intention of increasing the floor's thermal mass, in which heat could be stored during the day and slowly released at night; however, Florijn calculated in his report on one building's energy performance that the additional sandcrete flooring did not greatly improve the floor's thermal mass and was therefor unnecessary.

The buildings' indoor climates are working well for the most part but they have experienced some moisture and draft problems.

Florijn performed an energy system investigation on his father's house in the neighborhood. The house consisted of local, natural, and reused materials, such as straw bale walls. There was an uncertainty in how the walls would perform in the modeling vs. reality. After construction was completed, cold/ thermal bridges were detected in some straw bale earthship homes in the neighborhood, especially due to cracks that lowered the energy performance of the buildings. He concluded that the earthship construction was acceptable in terms of performance but did not perform as well as most modern materials and construction assemblies; this is not a good model for mainstream construction. From a performance perspective, polystyrene insulation would have been preferred due to its superior thermal properties.

Over the course of a building's life, an average of 43% of the energy used is for its operational energy.

Florijn had previously worked with Metabolic, located in Amsterdam. This company produces LCA's, material passports, and strategies for how to convert waste streams into usable materials, among other services.

Discussed the active and passive parts of buildings. Through the energy system, how will you generate and supply energy locally?

He recommended using a program called Design Builder, which allows you to build a BIM model and run simulations, including calculating the building's primary energy use and embodied energy, as well as producing graphs.

Material demand of the renewable energy transition:

An article by Metabolic concludes that there are not enough materials if we want to reach a zero carbon society. Florijn does not feel that this is an issue we should take on yet because we are not close to running out of materials at this moment.

The embodied energy of wind turbines and solar panels can be calculated by an energy invested metric; it takes a few years to make a return on the investment. There is 1:5 input energy to output energy ratio. To put things in perspective, this should be compared to the input to output energy ratio of oil. Previously, when oil was abundant, there was a ratio of 1:100. Oil is now becoming more and more difficult to extract. As a result, companies will run into economic issues: if it is too difficult, it becomes to expensive and the ratio decreases.

If the world can't sustain energetic growth, it can't sustain economic growth, which leads to economic collapse.

Renewable energy is expensive. Economic growth is related to renewables in which primarily renewable energy implementation can slow or stop economic growth.

He recommended the following articles / video:

- *"Circulaire Business Cases in de MRA" by Metabolic (retrieved from: https://www.metabolic.nl/publications/circulaire-business-cases-mra-bouw-sloopafval/)*
- *"The Energy Trap" by Tom Murphy (retrieved from https://dothemath.ucsd.edu/2011/10/the-energy-trap/)*
- *"French Engineer Schools Politicians on the Physics of Energy" (retrieved from https://www.youtube.com/watch?v=pggA6_9aW5c)*

ARKITEKTURGALAN 2019 IN STOCKHOLM, SWEDEN

Collection of notes from gala speakers and panel discussions: Micro instead of macro: decentralized strategies for sustainability.

Helena Bjarnegård (Boverket)
Working with humans as the central focus and architecture as a tool. Sustainability and quality should not be sacrificed to short-sighted economic gains.
Architectural programs are being created by multiple Swedish municipalities to make municipal comprehensive plans for sustainability more concrete and to be used as a tool/ a template for architecture and planning decisions.

Gert Wingårdh
20% of all plastic exists in and is used by the building industry. How much plastic do we need in our buildings, if at all?

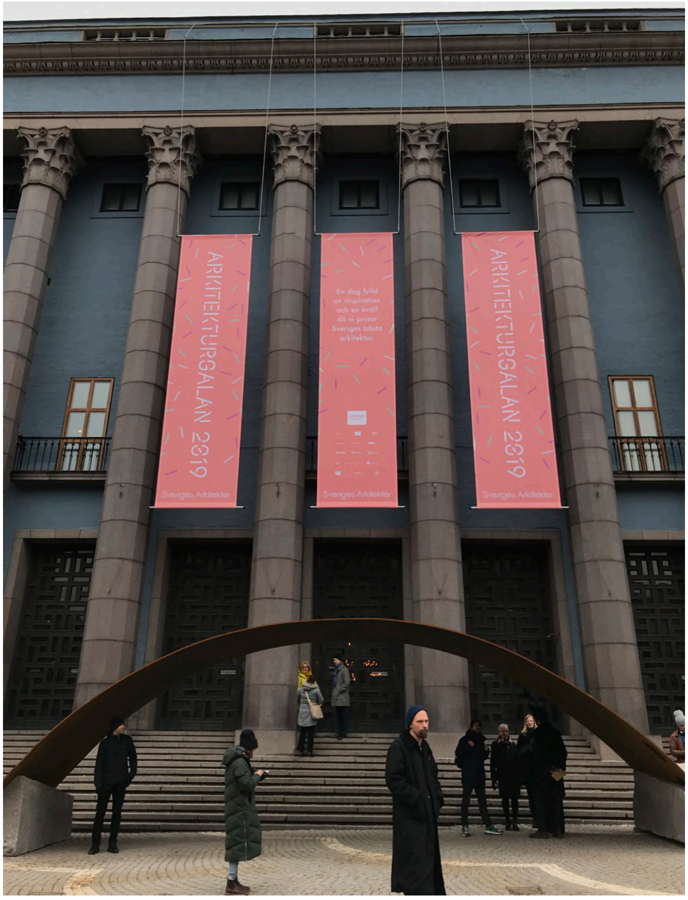
It is easy to spend a lot of others' money.
The building industry's climate fiasco: that buildings with 40 years left in their useful lives are demolished. One contributing factor could be buildings with too low ceiling heights that cannot be adapted and reused.
Consider the larger context vs. respective projects' sustainability goals.

Jan Christian Vestre
"Ingen kan göra allt men alla kan göra någonting."

Kerstin Kärnekull
Residential buildings should have warning labels just like cigarette packages. More people die in accidents at home than in traffic accidents.
Loneliness and isolation shortens life expectancy.
Fellowship can exist when there are communal rooms.

Rodrigo Garcia Gonzalez (Skipping Rock Lab)
Sharing your ideas with others helps ideas grow.

Maarten Gielen (Rotor Deconstruction)
- *When an architect wants to use marble to create architecture, a hole in the earth is created where the marble once was. Why is the space created in the quarry not considered architecture when the new building construction is?*
- *In Brussels, the life expectancy of office interiors is the time of the office lease (typically Belgian offices are rented out with no finishes). Rotor Deconstruction began as an architecture firm and became a material salvage and resale company when they realized the high turnover of offices and huge amount of waste of high quality materials. Rotor has a large warehouse and showroom (physical & online).*



Stockholm Concert Hall Entrance

Main Stage

- They must assess the worth of the materials they collect
- Cost of Risk (dismantling / handling) < Market Value
- The economy is absurd: the cost of packaging/ palletting & transporting reused CMU blocks (offered for free) is more expensive than the wholesale price and delivery of new CMU.
- The capital costs of Rotor's business are much higher than normal businesses.
- To make up for loss of material purchasing percentage for contractors when buying construction materials, Rotor needs to nearly double the price of reclaimed doors to make up for lost contractor earnings.
- Consider where salvaged materials originate from. Example: when reclaimed wood gained widespread popularity in the USA, companies bought Thai farmers' teak barns in large numbers in order to deconstruct them and ship them to North America for interior decoration.
- Foster & Partners sustainable city claims to be sustainable and net zero carbon, but this is only within the city's walls. A concrete factory (for the city's construction) and an airport are located outside of the boundaries. Can you consider it sustainable if part of a larger unsustainable infrastructure?
- Opalis (https://opalis.be/en) - ongoing research project with a network of companies working with reused materials. Many companies are already doing this. Working with ±200 companies selling secondhand in France, UK, Belgium, & the Netherlands.
- Standardized specification sheets are needed for used material resale. If multiple companies are selling the same materials using established standards, this will allow for public tendering.
- Decentralization of reuse work.
- New tower in Brussels being constructed from untransformed materials.

Demo Site → Washed → New Building Re-installation

Shigeru Ban

Shigeru is known as a sustainable architect given his work with paper products and low impact materials.

- Instead of concrete foundation, he used wooden boxes filled with sand (for a large pavilion in Germany).
- Project: Nomadic Museum featuring Gregory Colbert
  Rented shipping containers for 3 months at a time (locally) to temporarily create museums showing Colbert's work at multiple locations around the world that could then be disassembled and returned at the end of the exhibitions.
- Project: Tamedia office building in Zurich
  Constructed rigid connections in timber frame construction without any metal by sliding oval beams into pre-cut oval connections (which prevented rotation).
- Project: Aspen Art Museum in Aspen, Colorado
  Timber space frame with only one metal joint used per section
- Temporary vs. Permanent Structures
  -Temporary: a concrete structure by a "starchitect" that can be demolished if not loved.
  -Permanent: A paper structure loved by the people can be permanent if taken care of.
- When working in an earthquake-affected Asian country with few resources and a small budget, Shigeru used wooden door frames (which were approved as earthquake resistant) as standard structural wall units in buildings; the frames were then filled in with bricks for the bearing walls.

Michael Grahn (Danske Bank)

- The population in Sweden is increasing (mostly people 0-19 years and 80+ years), but the numbers show that Sweden will not be able to afford the multi-unit residential buildings needed to house them, given the income levels of these groups and the cost of construction of such buildings.
- A society without growth is a society without building.
- Uppsala Kommun has high standards for environmentally friendly design/ building (use them as a benchmark).

Conference Summary

- The lectures and discussions exhibited a great deal of self-criticism of the architecture and building industry, including discussions about segregated societies, the building industry's impact on the environment, economic barriers, and the creation and effect of various systems.
- The panelists had hoped for more open questions rather than the number of proposed solutions presented throughout the day.
- We have rationalized a consumption-based society so much that it is not (economically) worth it to reuse materials as such a society is too short-sighted.
- There has been a lot of discussion about technical solutions, but at the end of the day, it comes down to human behavior.
- As architects, we should not remove ourselves and observe society from afar but should become active and "get our hands dirty."

LA FERME DU RAIL WITH MARINE KERBOUA IN PARIS, FRANCE

The project under construction in Paris
March 2019

Marine is currently interning at Grand Huit Architects and working on a socially inclusive project on a site that used to be part of an old raised train line in Paris (known as the Petite Ceinture). The program has a number of innovative aspects including CHRS apartments, urban farming (to be carried out by future residents), building construction carried out by future residents and other homeless/ unskilled laborers to help them learn marketable skills, shared kitchen and living spaces, a ground floor "activity block" accessible by disabled people, an on-site restaurant and rooftop greenhouse, a stormwater cistern, a viaduct mushroom farm, and a neighborhood compost collection point. Most importantly (from this thesis' perspective) is the focus on using local, natural, recycled, and reused materials.

This type of housing (known as CHRS in French) is typically meant for a two year stay. It is a half-way residence prior to reintegration in a normal residence, but if an individual requires more (or less) time, there is no rules for the length of stay.

Marine's task in this project is to identify available reused materials and detail their applications in the building (mostly surface materials). Thus far she has visited a warehouse of salvaged material collected by a contractor over 50 years to choose bathroom tiles and provided unique detailed drawings for each bathroom in the project, in addition to proposing other reuse strategies as the project progresses.

She is also dealing with issues during construction, such as the failing roof pavers seen here. The salvaged pavers are chipping and cracking after installation, which could be due to a number of different reasons: improper vertical/ horizontal storage, storage temperature, or installation should have been on a sand or gravel bed. A great deal of money was spent on these pavers for storage and purchasing, which will now have to be remedied.

The construction does not seem to be detailed for future reuse. Surfaces, such as the wooden flooring and ceramic tile will be glued/ receive typical installations, therefore making continued reuse in the future more challenging.

Wood structure and framing sources:
- French Douglas from massif central / Limousin, France
- Épicéa massive wood from Massif du Jura / Vosges, France
- Épicéa (spruce) for gluelam structure from Sweden / Finland


Custom ordered compact straw bales used for wall insulation from a farmer in Fontainebleau, France (70km from the construction site)


Recycled textile acoustic insulation from by Métisse to be installed in unit party walls (this was more expensive than typical insulation)


Failing natural stone roof pavers on pedestals

APPENDIX II

Site

Existing Photos -
Detail plan -
SWOT Analysis -

KV. BJÖRKEN
MARIESTAD, SWEDEN

EXISTING PHOTOS & DETAIL PLAN

A detail plan, produced by a municipality's planning department, is a zoning document that defines how an area shall be developed, land uses, setbacks, building heights, etc.

The detail plan to the right depicts the city block, "Björken," in the center of Mariestad city, in which the thesis design proposal is located.

The photos below depict the existing site and the surrounding area.

Popular food store across the street from site on Björken

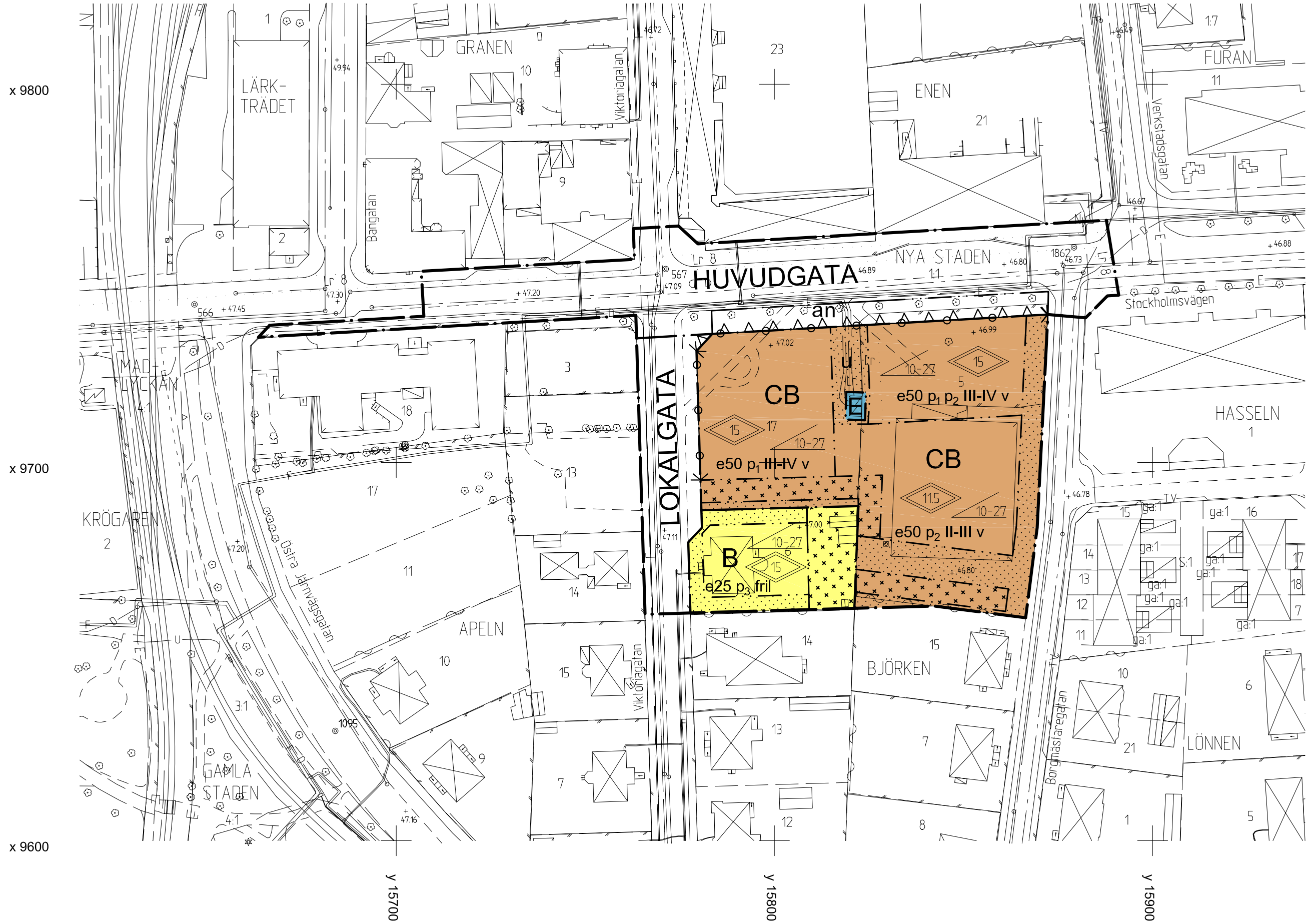
View from Stockholmsvägen of parking lots across from ICA food store, including the site on Björken

Looking east along Stockholmsvägen, past the chosen site. Multi-use residential, commercial, and service buildings line this part of the street.

The property beside the chosen site currently exists as an empty lot: partially overgrown and partially used as a temporary skate park and parking area.

The skate park on the empty lot beside the chosen site. Single family homes can be seen beyond.

KOPIA



Planbestämmelser

Följande gäller inom områden med nedanstående beteckningar. Där beteckning saknas gäller bestämmelsen inom hela planområdet. Endast angiven användning och utformning är tillåten.

Gränsbeteckningar

- Detaljplanegräns
- Användningsgräns
- Egenskapsgräns

Bestämmelser

Allmänna platser

- HUVUDGATA — Trafik mellan områden
- LOKALGATA — Lokaltrafik

Kvartersmark

- B — Bostäder
- CB — Kontor, butiker, service, föreningslokaler i bottenplan. Kontor, föreningslokaler och bostäder i övre plan.
- E — Teknisk anläggning

BEGRÄNSNINGAR AV MARKENS BEBYGGANDE

- Marken får inte bebyggas
- Marken får endast bebyggas med uthus och garage

Egenskaper

BEGRÄNSNING AV MARKENS BEBYGGANDE

u — Marken skall vara tillgänglig för allmänna underjordiska ledningar

MARK OCH VEGETATION

Markens höjd får inte ändras mer än +/- 0.4 m i föhållande till på plankartan redovisade höjder.

Parkeringsplats skall anordnas inom fastigheten. Parkering i källarplan är tillåten.

n — Träden får inte fällas. Träd får emellertid fällas om det angripits av sjukdom eller om trädet medför fara för liv eller hälsa. Återplantering skall ske för att ersätta borttaget träd.

UTNYTTJANDEGRAD/FASTIGHETSINDELNING

e00 — Största byggnadsarea i procent av fastighetsarea

PLACERING, UTFORMNING, UTFÖRANDE

Uthus, garage och transformatorstation får ej uppföras till större höjd än 3.0 m.

Dagvatten skall fördröjas och avledas trögt till kommunens anläggning enligt Policy för hantering av dagvatten i Mariestads kommun, antagen av Kommunfullmäktige 2005-12-19.

Ny bebyggelse skall utformas så att den ansluter till karaktärsdrag hos bebyggelse i omgivningen

- 0.0 — Högsta totalhöjd i meter
- 0.0-0.0 — Minsta resp. största taklutning i grader
- fril — Endast friliggande hus
- III-IV — Lägsta respektive högsta antal våningar
- p_1 — Byggnader skall placeras vid tomtgräns mot Stockholmsvägen och Viktoriagatan
- p_2 — Huvudbyggnaden skall placeras i inre förgårdslinje mot Borgmästaregatan.
- p_3 — Huvudbyggnaden skall placeras i inre förgårdslinje.
- v — Minst ett rum i varje lägenhet skall placeras mot gårdssidan, för en så kallad tyst sida
- In- och utfart får inte anordnas
- Byggnaden skall utformas dämpande så att högsta ekvivalenta ljudnivå ej överstiger 45 dbA inomhus dagtid och 30 dbA inomhus nattetid. Balkonger och uteplatser skall placeras och utformas så att den maximala ljudnivån inte överstiger 70dbA. (I enlighet med infrastrukturprop. 1996/97:53, antagen av riksdagen 1997.)

Genomförandetid

Genomförandetiden är 10 år från den dag planen vinner laga kraft

Ändrad lovplikt, lov med villkor

a — Marklov krävs för trädfällning

Grundkarta över
Björken 6 mm
i Mariestad

Upprättat av Tekniska förvaltningen/
Kart- och mätningsavdelningen
i maj 2007, Mariestads kommun

Sten-Gunnar Steenson
Mätningsingenjör

Skala 1:1000
Registerområde: Mariestad
Standardklass: II
Koordinatsystem: Mariestads Lokala
Höjdsystem: MH24
Fastighetsredovisning: 2007-07-31

BETECKNINGAR

- Fastighetsgräns
- Traktgräns
- Lr — Ledningsrätt
- ga Ny — Gemensamhetsanläggning resp. nyttjanderätt
- APELN 14 — Fastighetsbeteckning
- Viktoriagatan — Gatunamn
- Bostadshus resp. uthus
- Byggnad i allmänhet
- Skärmtak
- Transformator
- Trappa
- Skymd byggnadslinje
- Vägkant
- Järnväg
- Kantsten
- Stödmur
- Staket
- Häck
- +45.28 — Markhöjd
- Lövträd
- Rutnätspunkt
- 567 — Polygonpunkt
- E — Elledning
- D — Datakabel
- U — Utfors fiberkabel
- TV — Telekabel
- F — Fjärrvärmekulvert
- Spillvatten-, vatten- och dagvattenledning

Likheten med originalet bestyrkes

ANTAGANDEHANDLING

DETALJPLAN FÖR
Del av Kv Björken
MARIESTAD, MARIESTADS KOMMUN
Upprättad av Kommunledningskontoret i mars 2008

Linda Kjerfve
Planarkitekt

Beslutsdatum	Instans
GODKÄNNANDE 2008-05-29	KS
ANTAGANDE 2008-06-16	KF
LAGA KRAFT 2008-07-21	KF
PLANAVGIFT JA ☒ NEJ ☐	

Skala 1:1000
0 10 20 30 40 50 100 m

462

SWOT ANALYSIS

SWOT analysis stands for strengths, weaknesses, opportunities, and threats.

During the Fall 2018 Local Context course at Chalmers, the students collectively participated in the creation of this list based on a month long period of analysis of the region surrounding Mariestad municipality.

"The analysis considered economic, environmental, political, and social factors, in addition to establishing an understanding of the rural and urban built environment." (Jonasson, Josefsson, & Marklund, 2019, p 8)

The points most relevant to this investigation have been highlighted.

STRENGTHS

- Fertile soil for agriculture (incl. centrally located in urban areas)
- Tourism
- Proximity to nature (green & blue structures)
- Vänern (ecosystem services, tourism, shipping, fresh water)
- **Municipality committed to (engaged in) being a model area for sustainability as defined by UNESCO**
- **Green energy ambitions**
- Biodiversity
- **Well connected to regional infrastructure**
- Possibility for higher education in specific fields
- Small scale community (few steps between decision makers & inhabitants)
- Affordable housing compared to larger cities
- Family-friendly (pre-schools)
- Walkable distances within the city
- **Cultural heritage**
- Integration projects
- **Existing industrial facilities & infrastructure**
- Active / strong associations (sports, crafts, scouts)

WEAKNESSES

- Car dependency
- Physical / mental / social barriers (Tidan, big roads, railroads, industrial area)
- Inaccessible shoreline
- **Lack of meeting places**
- Seasonal demand
  - **- Empty parking lots**
  - **- Closed / open meeting places**
  - - Public transportation
  - **- Consumer demand**
  - - Tourism & gentrification
  - - Lack of activities
- Broken housing cycle
- Existing specialized education does not motivate people to stay in Mariestad due to the lack of corresponding jobs.
- Low percentage of Mariestad's population has a high education, affecting tax revenues
- Limited access to services (especially in the countryside)
- **Lack of social inclusion**
- Limited public transport
- Lack of connection to national infrastructure (airports)
- Lacking infrastructure for bikes & pedestrians
- Insufficient infrastructure for sewage and storm water management
- Noise & air pollution
- **Aging population**
- **Migration to bigger cities**
- Homogeneous agriculture (monoculture)

OPPORTUNITIES

- Development of higher education
- Digitalization
  - Work / study / shop from a distance
- Technological development
- **Renewable energy demand**
- **Västra Götaland Regionen's research and investment in sustainability**
- **Trend of circular / green economies (DIY, local production, eco-tourism, self-sufficiency, handicraft, knowledge, ruralization)**
- **Trend of lifestyle of health & sustainability**
- **Sense of urgency regarding sustainability issues**
- Prolonged agricultural growing & tourism season due to warmer climate
- **Regional growth will benefit Mariestad (focus on Skövde)**
- Migration (global mobility)
- Growing trend of tourism & counter-trend of "stay-cation" / "hemester"

THREATS

- Climate change effects:
  - Flooding / drought / erosion
  - Crop failures
  - Increased instances of extreme weather
  - Decreased tourism
- Pollution
- **Cautious approach to change due to a perceived sense of powerlessness**
- **Climate change denial in positions of power (commercially & politically) is slowing down sustainable development**
- Loss of connection to nature
- **Consumerism**
- **Aging population - dependency ratio is unbalanced**
- **Depopulation due to urbanization**
- **Centralization - loss of local specificity:**
- **- Local political, social, identity, commercial**
- **- Loss of local services**
- Global trends of polarization & individualization leading to:
  - Decreased trust between people and of authorities
  - Segregation
  - Loneliness & isolation
  - Weaker family bonds
  - Counter-trends of co-housing & D.I.Y. culture
- **Uninformed planning leads to reckless land use**
- **Dominance of a few large companies: non-resilient job market**

APPENDIX III

Life cycle analysis calculations

sun studies

PRELIMINARY CALCULATIONS: LIFE CYCLE ANALYSIS

DESCRIPTION

Comparing LCA calculations between a new building designed with reused materials and the same new building using new materials is a tangible method for exhibiting the benefits of reuse.

The spreadsheets to the right show simple LCA analysis calculations for early design stages of solely the structure. This thesis proposes a structure made from reclaimed solid timber that has been cut and glued to produce glued solid timber elements after collection. According to Kauschen (personal communication, March 2019), there is industry-wide disagreement over how to calculate the LCA of reused materials; at this time, there is no standard method of calculating the life cycle analysis of materials that may continue use after their first intended use.

COMPARISON

Given that some processing energy is required for glued solid timber production, it has been calculated with estimated stacked & doweled wood board elements with standard values of:

GWP: -0.156 kg CO_2equv/kg
Stored Potential: -1.5 kg CO_2/kg
Materials + transportation: **-29 368 kg CO_2/50 years**

Transportation of the timber from the collection points (dismantled buildings) to the Moelven wood factory in Töreboda, then to Mariestad have been estimated at approximately 100km. Given that the material is reused, it is likely that the environmental cost of the transportation would be higher than the re-processing energy required.

A new glulam structure of the same size (GL30c profile) would is calculated as follows:

GWP: 0.191 kg CO_2equv/kg
Stored Potential: -1.45 kg CO_2/kg
Materials + transportation: **37 342 kg CO_2/50 years**

In this case, transportation is calculated as coming directly from the Moelven factor, 18km from the construction site.

The material in the steel structure LCA analysis used for comparison is roughly estimated to consist of 1/3 of the volume of the wood structure and is calculated as a high steel alloy product.

GWP: 4.95 kg CO_2equv/kg
Stored Potential: 0 kg CO_2/kg
New steel structure: 5 155 878 kg CO_2/50 years

However, due to structural calculations differing between metal and wood elements, this is not a reliable estimate. A study done by Hassan & Johansson (2018) calculated and compared the economic and environmental aspects of both structural options. In finding the corresponding glulam and steel loads carrying predetermined span lengths rather than comparing cross-sections which vary with the spans required, they showed the following (the numbers below have been extracted as applicable to the thesis design's structural proposal):

Laminated wood structure (GL30c):

Span:	4m
GWP:	63.9 kg CO_2equv/kg
GWP w/ Stored Potential:	-193.2 kg CO_2/kg

vs.

Steel structure (estimated HEA200 profile)

Span:	4m
GWP:	101.5 kg CO_2equv/kg
Stored Potential:	0 kg CO_2/kg

For a span of 4m, The embodied energy of steel is ±1.6x that of standard glulam wood (w/out carbon storage inclusion)

ENERGY & BALANCE

The spreadsheet also estimates the energy demand of the office over the span of 50 years and balances this with the on-site PV energy production over the same time span. Given that the LCA is only calculated for the structure, the total kg CO_2/50 years balance shown on the top left of each spreadsheet is not correct; all of the building's materials would need to be included in the calculations to understand the full picture.

CONCLUSION

A building with a laminated wood structure has significantly lower embodied energy than the same building with a steel structure. Given the difficulty in calculating the embodied energy of reused materials, it is very difficult to compare a the same structure between new and reused laminated wood, as all of the values contributing to the total embodied energy would be project-specific in a reuse situation. One may assume that since no new material is procured when constructing with reused material, the embodied energy from resource extraction, transportation, processing, etc. would be significantly less than a construction with new materials.

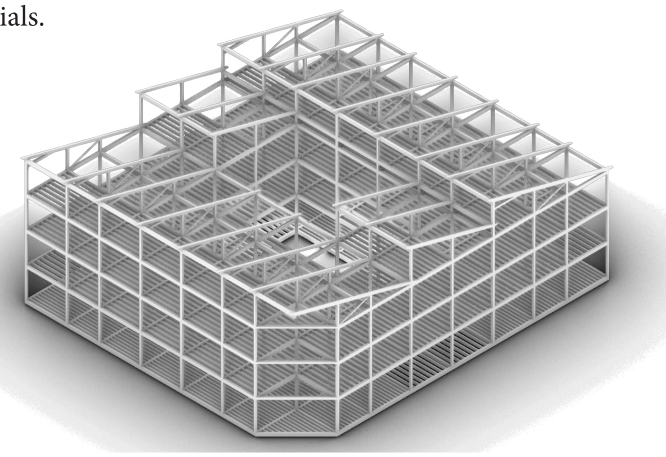


Figure X: Glued solid timber wood structure

LCA OF PROPOSED STRUCTURE: GLUED SOLID TIMBER

Figure X

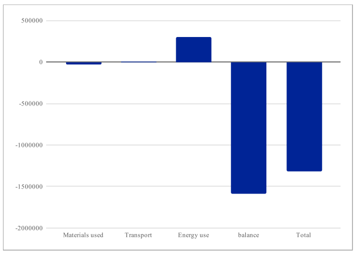
Simple LCA analysis for early stages

Fill in grey cells

Results

Emissions

Materials used	**-32724**	kg CO2 / 50 y
Transport	**3356**	kg CO2 / 50 y
Energy use	**301077**	kg CO2 / 50 y
balance	**-1588817**	kg CO2 / 50 y
Total	**-1317108**	kg CO2 / 50 y



New Steel Structure_Materials LCA

Use materials in database below, Volume in m3

Leadtime	50	years
Storage factor	50	% (100 % is 1,6 kg per kg cellulose)
Transp	12	%, normal is between 5-20 %
Building site	8	%, normal is between 5-20 %
Transport	0.08	kg/ton km

	Building part	Material nr	Volume m3 Surface Area * Tl	Transport km	Kg CO2eqv	Kg Stored CO2	CO2 trp
Structure	Glued Solid Timber	9	419.533	100	-32724	-314650	
	Standard Laminated Wo	7	0	18	0	0	
	Steel [high alloy]	121	0	175	0	0	
					0	0	
					0	0	
					0	0	
					0	0	
					0	0	
					0	0	
					0	0	

Energy

Use kWh/m2, m2 and type of energy in list

Energy types	kWh/m2	m2	Number	GWP	
Function electricit	50	3717	3	3717	0.02
Hot water	8	3717	3	594.72	0.02
Heat	14	3717	3	1040.76	0.02
Cooling	9	3717	3	669.06	0.02
			1	0	0
			1	0	0
			1	0	0
			1	0	0
			Total:	**6021.54**	kg/year
				301077	kg tot
			GWP		

Balance

Balance of energy production

Type of balance			factor	
PV production	311,194	kWh,	-0.092	-28629. kg CO2/year
Wind electricity	0	kWh,	-0.112	0 kg CO2/year
Solar heat*	0	kWh,	-0.03	0 kg CO2/year
Off-site pv**	0	kWh,	-0.1	0 kg CO2/year
Off site wind**	0	kWh,	-0.112	0 kg CO2/year
Energy balance	**-28629.848**	kg CO2/year		
Off site comp**	**0**	kg CO2/year		
Carbon storage***	**-3146**	kg CO2/year		
Total balance	**-31776**	kg CO2/year		
	-1588817	kg CO2 total		

COMPARISON: LCA OF NEW GLULAM STRUCTURE

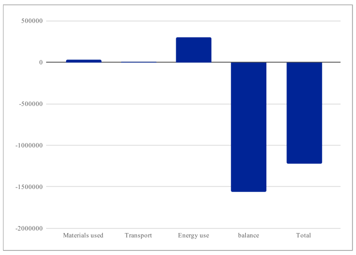
Simple LCA analysis for early stages

Fill in grey cells

Results

Emissions

Materials used	**34456**	kg CO2 / 50 y
Transport	**520**	kg CO2 / 50 y
Energy use	**301077**	kg CO2 / 50 y
balance	**-1562282**	kg CO2 / 50 y
Total	**-1226229**	kg CO2 / 50 y



New Steel Structure_Materials LCA

Use materials in database below, Volume in m3

Leadtime	50	years
Storage factor	50	% (100 % is 1,6 kg per kg cellulose)
Transp	12	%, normal is between 5-20 %
Building site	8	%, normal is between 5-20 %
Transport	0.08	kg/ton km

	Building part	Material nr	Volume m3 Surface Area * Tl	Transport km	Kg CO2eqv	Kg Stored CO2	CO2 trp
Structure	Glued Solid Timber	5	0	100	0	0	
	Standard Laminated Wo	7	419.533	18	34456	-261579	
	Steel [high alloy]	121	0	175	0	0	
					0	0	
					0	0	
					0	0	
					0	0	
					0	0	
					0	0	
					0	0	
					0	0	
					0	0	
					0	0	

Energy

Use kWh/m2, m2 and type of energy in list

Energy types	kWh/m2	m2	Number	GWP	
Function electricit	50	3717	3	3717	0.02
Hot water	8	3717	3	594.72	0.02
Heat	14	3717	3	1040.76	0.02
Cooling	9	3717	3	669.06	0.02
			1	0	0
			1	0	0
			1	0	0
			1	0	0
			Total:	**6021.54**	kg/year
				301077	kg tot
			GWP		

1	Energy source	0
2	Nordic electricity	0.125
3	Swedish normal	0.02

Balance

Balance of energy production

Type of balance			factor	
PV production	311,194	kWh,	-0.092	-28629. kg CO2/year
Wind electricity	0	kWh,	-0.112	0 kg CO2/year
Solar heat*	0	kWh,	-0.03	0 kg CO2/year
Off-site pv**	0	kWh,	-0.1	0 kg CO2/year
Off site wind**	0	kWh,	-0.112	0 kg CO2/year
Energy balance	**-28629.848**	kg CO2/year		
Off site comp**	**0**	kg CO2/year		
Carbon storage***	**-2616**	kg CO2/year		
Total balance	**-31246**	kg CO2/year		
	-1562282	kg CO2 total		

*: Only to be used if connected to district heating grid
**: May only compensate for maximum 25 % of emissions
***: May only compensate for emissions of materials

COMPARISON: LCA OF NEW STEEL STRUCTURE

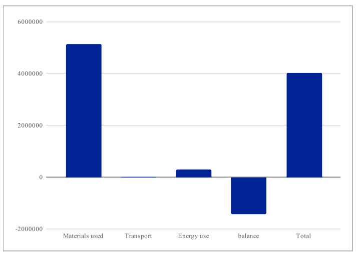
Simple LCA analysis for early stages

Fill in grey cells

Results

Emissions

Materials used	**5135130**	kg CO2 / 50 y
Transport	**20748**	kg CO2 / 50 y
Energy use	**301077**	kg CO2 / 50 y
balance	**-1431492**	kg CO2 / 50 y
Total	**4025463**	kg CO2 / 50 y



New Steel Structure_Materials LCA

Use materials in database below, Volume in m3

Leadtime	50	years
Storage factor	50	% (100 % is 1,6 kg per kg cellulose)
Transp	12	%, normal is between 5-20 %
Building site	8	%, normal is between 5-20 %
Transport	0.08	kg/ton km

	Building part	Material nr	Volume m3 Surface Area * Tl	Transport km	Kg CO2eqv	Kg Stored CO2	CO2 trp
Structure	Glued Solid Timber	5	0	100	0	0	
	Standard Laminated Wo	7	0	18	0	0	
	Steel [high alloy]	121	133	175	5135130	0	
					0	0	
					0	0	
					0	0	
					0	0	
					0	0	
					0	0	
					0	0	
					0	0	
					0	0	
					0	0	

Energy

Use kWh/m2, m2 and type of energy in list

Energy types	kWh/m2	m2	Number	GWP	
Function electricit	50	3717	3	3717	0.02
Hot water	8	3717	3	594.72	0.02
Heat	14	3717	3	1040.76	0.02
Cooling	9	3717	3	669.06	0.02
			1	0	0
			1	0	0
			1	0	0
			1	0	0
			Total:	**6021.54**	kg/year
				301077	kg tot
			GWP		

1	Energy source	0
2	Nordic electricity	0.125
3	Swedish normal	0.02

Balance

Balance of energy production

Type of balance			factor	
PV production	311,194	kWh,	-0.092	-28629. kg CO2/year
Wind electricity	0	kWh,	-0.112	0 kg CO2/year
Solar heat*	0	kWh,	-0.03	0 kg CO2/year
Off-site pv**	0	kWh,	-0.1	0 kg CO2/year
Off site wind**	0	kWh,	-0.112	0 kg CO2/year
Energy balance	**-28629.848**	kg CO2/year		
Off site comp**	**0**	kg CO2/year		
Carbon storage***	**0**	kg CO2/year		
Total balance	**-28630**	kg CO2/year		
	-1431492	kg CO2 total		

*: Only to be used if connected to district heating grid
**: May only compensate for maximum 25 % of emissions
***: May only compensate for emissions of materials

SUN STUDIES

DESCRIPTION

Simple sun studies were used to understand the amount of shading and daylight on the different portions of the building over the course of the seasons and days.

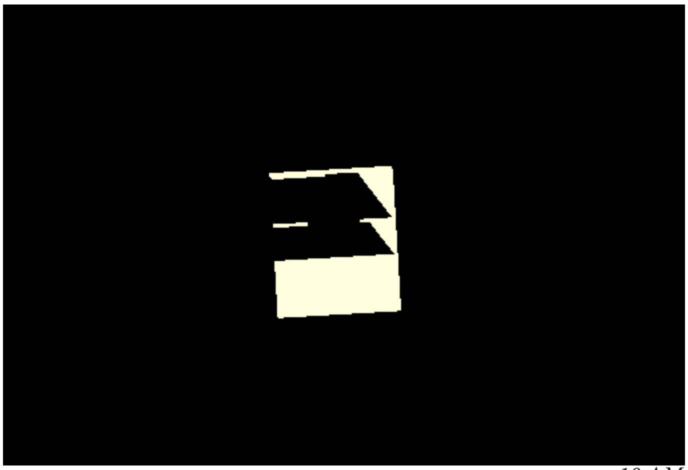
For a good indoor environment, an average daylight factor of 2 should be present throughout the day. Proper indoor daylighting boosts the health and productivity of the inhabitants. While extensive indoor daylight modeling (as can be performed with Velux daylighting tool) was not part of this study, this would be required as a future step to ensure a enough daylight penetrates the work areas.

The studies here show that some daylight typically reaches the atrium's eastern, southern and western facades during the spring, summer, and fall but during the winter days, the atrium and large portions of the BIPV roof are left in shadow.

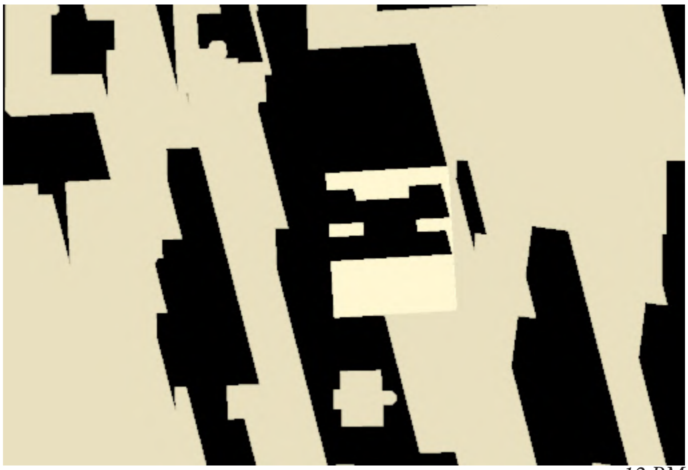
During most of the year, the majority of the roof's PV panels are unhindered by shade.

Additionally, glare and overheating from direct sunlight on the eastern, southern, and western facades are a concern, as the building receives no shading from nearby buildings or landscape elements. Window shading is required to improve the interior environment: vertical louvers on the east and west facades and horizontal shading on the southern facades.

WINTER SOLSTICE: DECEMBER 21

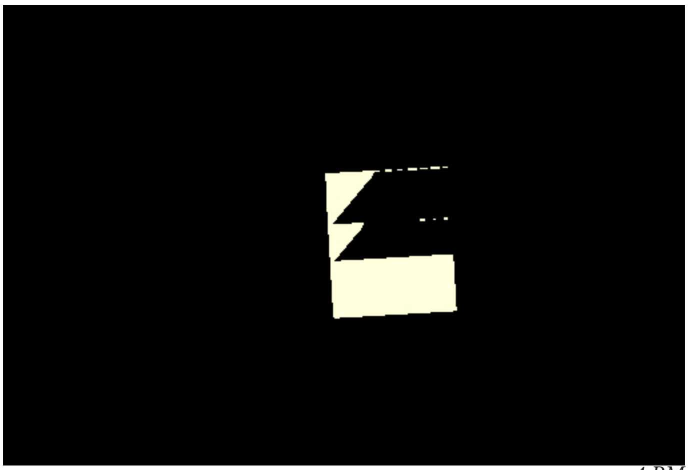


10 AM



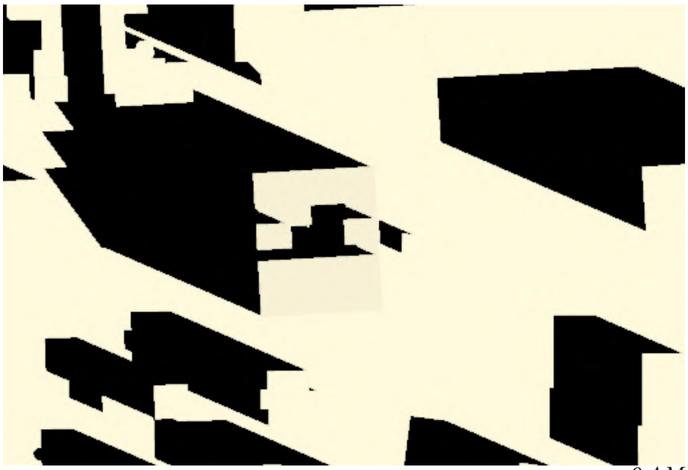
12 PM

3 PM



4 PM

EQUINOX: MARCH 21



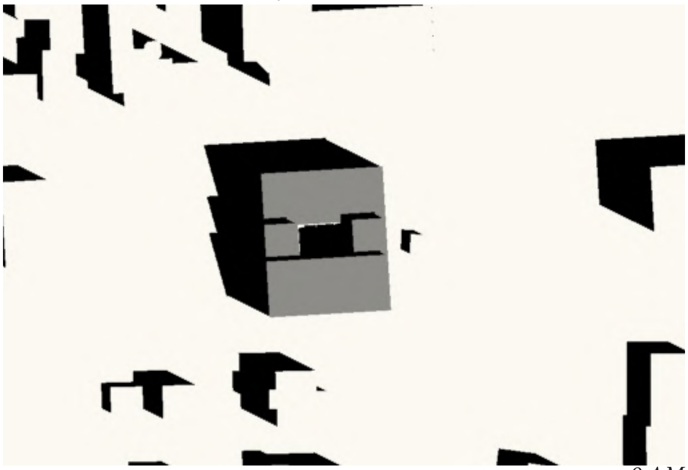
9 AM

12 PM

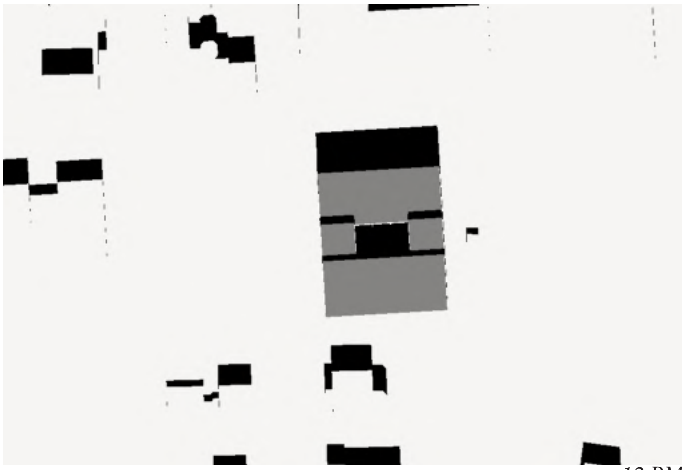
3 PM

6 PM

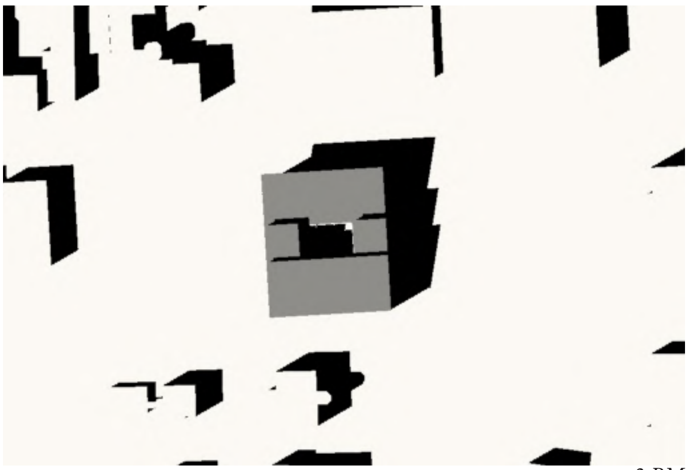
SUMMER SOLSTICE: JUNE 21



9 AM



12 PM



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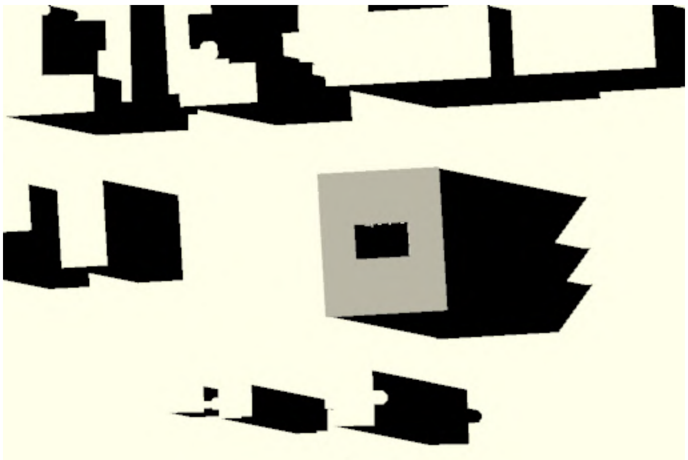

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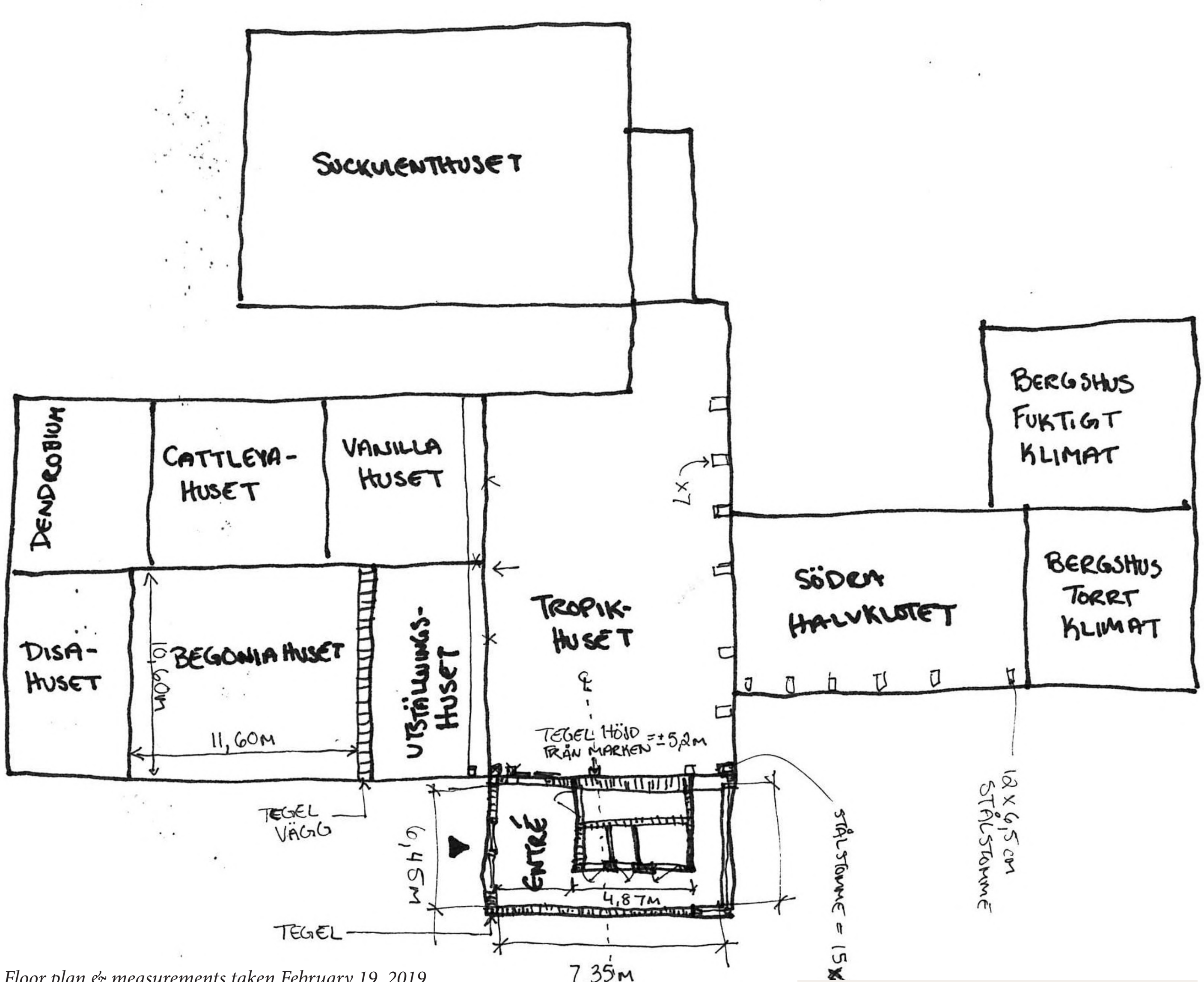
APPENDIX IV

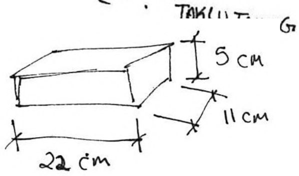
Material inventories

MATERIAL INVENTORIES OF BUILDINGS

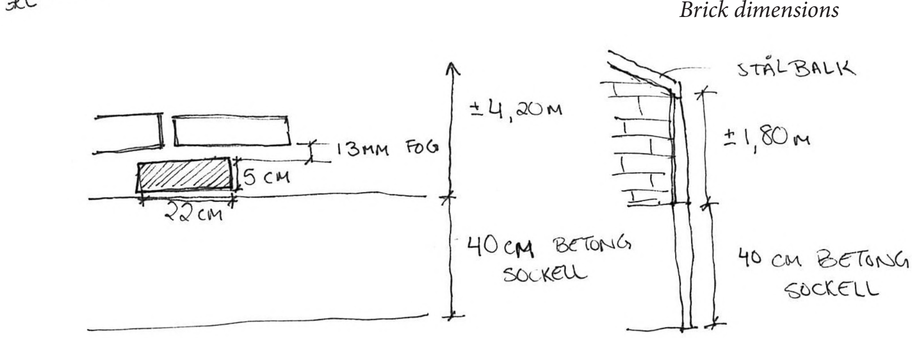
MATERIAL INVENTORY OF THE GREENHOUSE AT GÖTEBORG'S BOTANICAL GARDEN



Floor plan & measurements taken February 19, 2019



Brick dimensions



Elevation sketches

X 12x6.5cm steel beams & columns
X 15x25cm steel beams & columns
X bricks
X m² single pane glass
X m² terracotta tiling
X m 20cm Ø building service pipe
X Toilets
X Sinks
X Faucets
X Glass & steel doors
....

Material sizes & amounts

(Area accessible to public)
Building Volume: 5319 m^3
Floor Area: 1311 m^2
Roof Area: 1460 m^2
Wall Area: 953 m^2
Year of construction: 1981
Greenhouse exhibition floor area: 9100 m^2

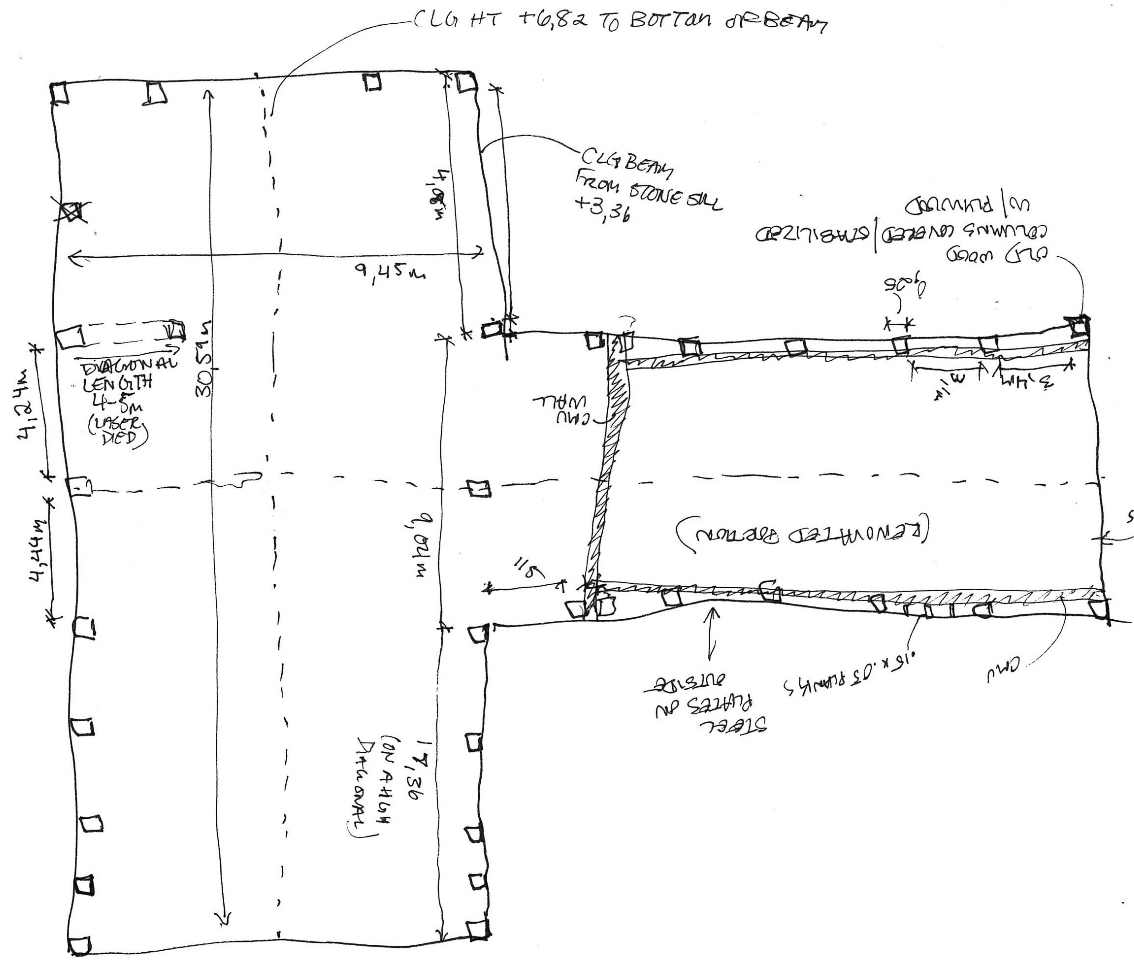
Materials: Single pane glass, concrete foundation, steel structure, brick wall infill, terracotta tiling, piping for building services, glass & steel doors

MATERIAL INVENTORY OF BARN B IN VARA, SWEDEN

Barn B

Building Volume: 2634 m^3
Floor Area: 516 m^2
Roof Area: 580 m^2
Wall Area: 495 m^2
Year of construction & type: Early 1900's, Timber
Renovated: 1987 & 2000's

Materials: timber structure, bolts, wooden plank facade, wood doors, single pane glass windows, CMU wall infill, stone foundation, poured concrete floor, plywood, corrugated steel panels, metal doors

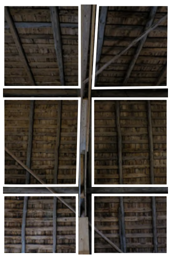


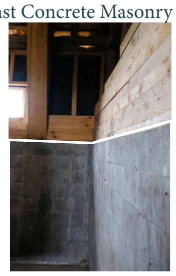
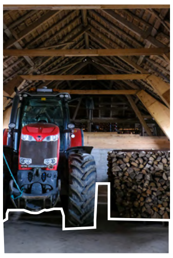
Floor plan & measurements taken March 8, 2019

Reuse of Building Materials

*Materials marked with * should be prioritized*

Building	Barn B
Year of Construction	196x
Location	Vara, Sweden

Material	Amount	Reuse Potential	Handling (dismantling process req'd)
Wood structure (main)  	34 vertical truss components @ 4.78m W x 6.42m H w/ ±.2m x .24m timber crossections 2 Purlins @ 25m L each 2 Purlins @ 26m L each 4 Purlins @ 31m L each w/ connections & ±.2m x .24m timber crossections	Structure Good condition	Unbolt from connected wooden elements
Wood rafters, battens & sheathing  	124 Rafters @ 5m L each 16 Rafters @ 4m L & less (tapered) w/ ±.1m x .1m timber crossections Sheathing Area: 580m² @ 2 layers of .25m thick each Batten Area: 580m² @ .35m O.C.	Structure Good condition	Unbolt from connected wooden elements
Wooden doors  	1 pair @ 4.75m W x 5m H 1 pair @ 4m W x 2.5m H 1 pair @ 4m W x 3m H	Doors Acceptable condition w/ some water damage @ bottom	Unscrew from frame
Wooden plank siding 	Length of siding: ±65m Planks @ ±.25m thick x 3.5m L	Siding Average condition w/ water damage @ bottom	Remove nails from structure Requires future paint maintenance (continuously)
Metal doors 	1 pair @ 4m W x 5m H	Doors Great condition	Unscrew from frame Shop painted, requires little maintenance
Corrugated metal siding 	Length of siding: ±52m Area of siding: ±182m² Panels: ±.4mm thick x 2.5m H x 1m W	Siding Great condition	Remove screws from structure Shop painted, requires little maintenance
Terracotta Roof Shingles 	Renovated Section Area: ±307m² Original Section Area: ±273 m²	Roofing, facade material, structural aggregate Majority poor condition	Unclip from wooden structure Dangerous roof condition

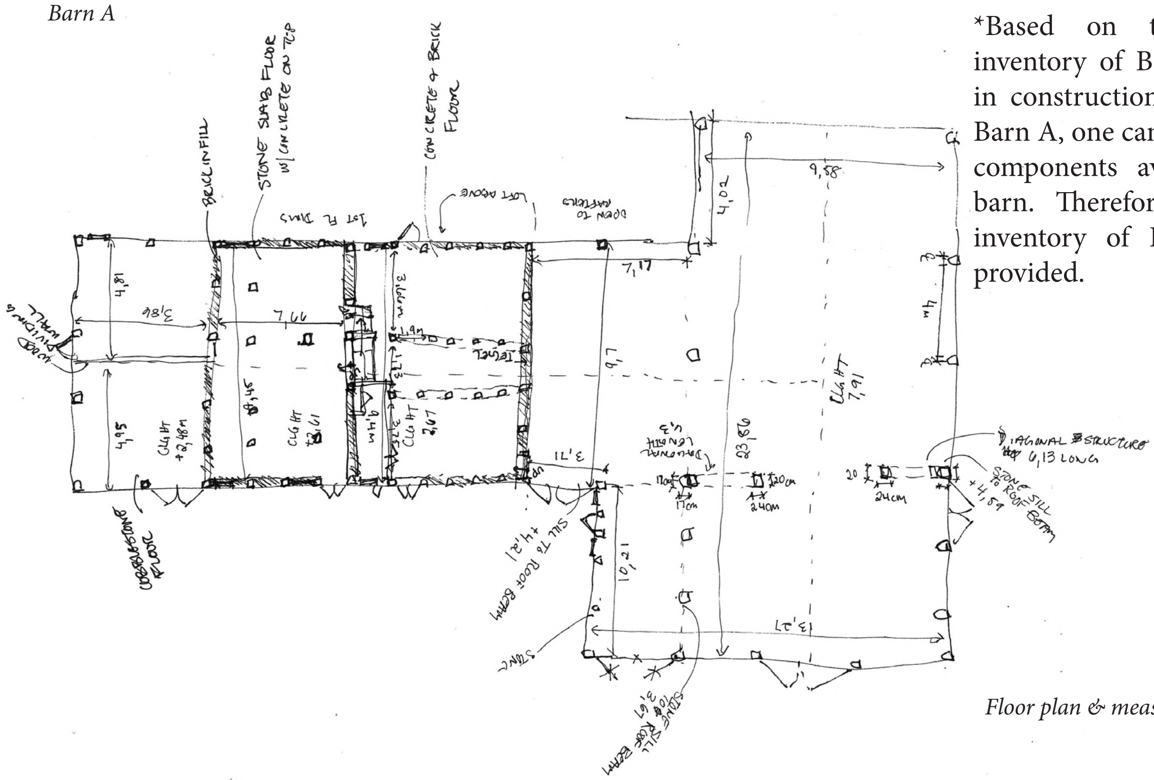
Reuse of Building Materials			
*Materials marked with * should be prioritized*			
Building	Barn B		
Year of Construction	196x		
Location	Vara, Sweden		
Material	**Amount**	**Reuse Potential**	**Handling (dismantling process req'd)**
Stone foundations blocks 	22 Blocks @ .5m W x .5m H x ±.5m D	Structure, foundation Excellend condition	Remove wooden blocks from joints
Precast Concrete Masonry Units 	Area: 86.5m^2 @ .2m x .19m x .4m each	Structure Excellent condition	Dislodge mortar and dismantle blocks
Poured Concrete Floor 	Area: 220m^2 @ ±.5m thick	Crushed aggregate for road or building foundation fill Excellent condition	Demolish and crush
Wooden Plank Studs 	Length of studded wall: ±38.6m Planks @ .15m D x .05m thick x 1.56m H @ .6m on center	Structure for interior or exterior wall Good condition	Remove nails from structure Pine wood has been stored in covered area in unconditioned building
Structure Stabilization 	Plywood panels: varying sizes covering (15) 5m diagonals each Beam planks & sill plates @ ±.15m D x .05m thick x varying lengths	Stucture or sheathing Good condition	Unscrew or remove nails Pine wood and plywood has been stored in covered area in unconditioned building
Windows 	6 Units @ .75m H x 1.5m W each 1 Unit @ .75m H x .75m W	Fenestration Good condition	Remove nails from frame Single pane window& would not meet U-Value requirements

MATERIAL INVENTORY OF BARN A IN VARA, SWEDEN

Barn A

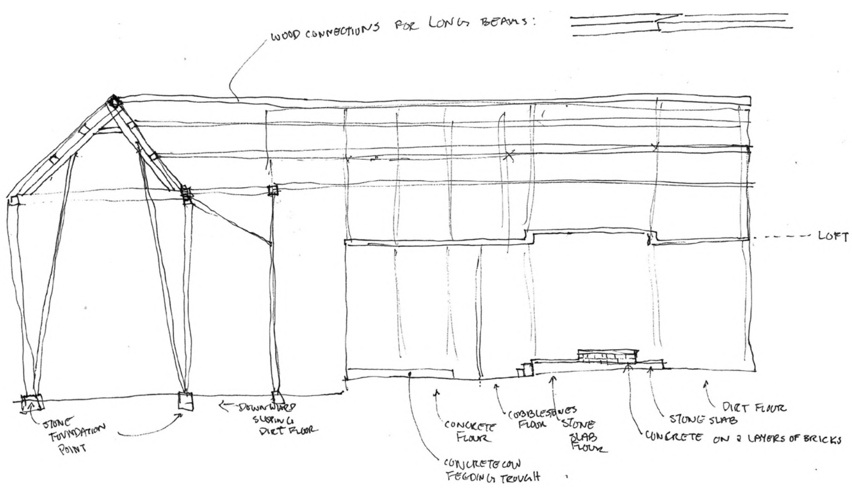
Building Volume: 3583 m^3
Volume of wood in structure: 420m^3
Ground Floor Area: 600 m^2
Roof Area: 780 m^2
Wall Area: 575 m^2
Year of construction & type: Late 1800's or early 1900's, Timber
Renovated: (roof) late 1900's

Materials: timber structure, bolts, wooden plank facade, wood doors, single pane glass windows, brick wall infill, stone foundation, stone floor pavers, poured concrete floor



*Based on the detailed material inventory of Barn B, which is similar in construction style and materials to Barn A, one can understand the various components available in the second barn. Therefore, a detailed material inventory of Barn A has not been provided.

Floor plan & measurements taken March 8, 2019



Section

Form Follows Availability
The Reuse Revolution

Spring 2019

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