Ecological Tectonics: Rethinking Construction through Material Reuse, Recycle, and Reclaim

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ABSTRACT: *Over the past two decades, the global demand for mineral-based building materials has experienced a threefold increase, with three materials – concrete, steel, and aluminum – alone contributing a significant portion of global carbon dioxide emissions at 23% (IEA 2018). The pressing environmental predicament has instigated architects and builders to reevaluate the relationship between material, the environment, construction processes, and labor. Though there has been a growing professional responsibility to prioritize ecologically conscious architectural practices, often conveyed through prescribed formulas such as building energy simulations and the LEED rating system, comprehending the environmental impact and assuming a responsible approach is becoming increasingly challenging.*

The paper presents a pedagogical experiment, developed in the form of an architecture seminar, that seeks to redefine and examine the concept of sustainability through the lens of material circularity. The seminar explores three distinctive approaches to building materials and construction, each aimed at rethinking conventional methodologies. The first approach, assembly for reuse, challenges the conventional idea of permeance by considering construction and deconstruction as equal partners. The second approach, upcycle material construction, repurposes discarded and obsolete products as building components. The third approach, reclaimed material construction, focuses on salvaging building materials through the careful process of dismantling and demolition, transforming them into new building elements.

The seminar employs a bottom-up learning and construction strategy, incorporating "found materials" such as waste (fabric, paper, plastic, and construction debris) and standardized building products (lumber and concrete cinder block) to construct full-scale wall mock-ups. Through these operations and building techniques, the seminar seeks to challenge the traditional use of fossil-based and petroleum-based materials and discover new material possibilities and tectonics. While creating a truly circular value system in construction is a complex and challenging task, the pedagogical objective is to engage students in raising awareness about material ecology and the construction process, thereby laying the foundation for future practices and contributing to finding solutions to environmental problems.

KEYWORDS: Sustainability, Circular Construction, Material Reuse, Material Ethics, Pedagogy

1. PEDAGOGICAL SHIFT

1.1 Towards material circularity

Through the progress of technology and streamlining production, fabrication, and assembly, the extraction and manufacturing process of building materials is often overlooked in our material choices. Hence, the conventional materials adopted in architectural education are frequently viewed as omnipresent and limitless. This narrow perspective deters the architecture discipline from recognizing the environmental impact of their actions and perpetuates the contemporary building practice with a receptive attitude and indifference toward material sourcing.

In light of the pressing need for accountability in the use of carbon-intensive materials, revamping the current pedagogical approach towards the teaching of materials in the way how and why has become increasingly crucial. The curricula for design and building technology must evolve to provide a comprehensive understanding of material ecology, fostering a newfound connection between architects and materials. To mitigate waste and extend the lifespan of materials, it is necessary to embrace recovery-oriented design and construction by exploring biogenic materials and reusing components in the built environment. Pedagogy must focus on establishing a framework that prioritizes physical and technical constraints, allowing students to consider a wide range of factors with a focus on the impact of their choices. By addressing questions of material adaptability and constructability early in the design process, students are propelled out of the conceptual and representational phase and into the search for sustainable solutions that align with the environmental and stewardship values of society.

1.2 Course structure

The pedagogical setting and explorations featured in this paper were part of a seminar entitled "Wall Craft," offered to students in the Department of Architecture at Kansas State University. The seminar was held once a week for three hours and was open to fourth and fifth-year architecture students. The course delved into the design and creation of various interior and exterior wall systems, focusing on material obsolescence and circularity and the potential to create alternative ways to construct walls. The wall has long served as a site of experimentation and innovation in architecture, and this seminar aimed to deepen students' understanding and engagement with building materials that minimize their environmental impact and promote sustainable design practices.

The course commenced with a series of discussions focusing on topics such as circularity, labor, constraints, and constructability. This was achieved through a combination of readings, an environmental impact assessment, and an examination of built precedents. Following a comprehensive introduction to the concept of material circularity, the course shifted its focus to the principle of 'craft as research.' This research was broken down into two components: prototyping and wall fabrication. The first study engaged in hands-on experimentation and testing of locally accessible materials, using prototypes to explore the materials' properties and potential. The students worked in pairs to construct the multiple prototypes, which were at a scale of 2-4 ft (0.61-1.22m) tall. The prototypes tested various concepts of assembly for reuse, upcycling, and construction with reclaimed materials. This included innovative designs such as a screen system made from sliced fence posts, cladding made from papercrete through recycling paper, and a wall cast with construction debris (e.g., Fig 1). The multiple rounds of testing sharpened the students' problem-solving and critical-thinking skills, encouraging them to challenge conventional material culture and usage.

The second part of the course was devoted to the creation of a 6ft (1.82m) tall mock-up that exemplified the principles of material reuse, recycling, or reclaiming. While participants were given the freedom to choose their materials, they were also encouraged to utilize readily available resources within their local or regional area to challenge conventional notions of material obsolescence. This provided an opportunity to cultivate a more positive impact on the life cycle assessment through the creation of a Material Passport, which would enable tracking and management of material flows and reduce transportation mileage. In the pursuit of practical knowledge and technical limitations, building mock-ups were envisioned to unveil and demonstrate various aspects of the application, disconnecting from the actual building (Geiser 2021).

Figure 1: First prototypes through precedent studies and material experimentations. (Author 2022)

1.3 Assessment of environmental impact

A succinct analytical examination was conducted to evaluate the environmental impact of conventional material utilization. The study critically analyzed existing and pre-existing material types in relation to wall assembly methods, exploring various platforms and graphs for evaluating material lifespan and carbon footprint. The course introduced the students to the Construction Material Pyramid[1], an interactive online tool developed by the Centre for Industrialised Architecture (CINARK) at the Royal Danish Academy (e.g., Fig 2). This interface enables visualizing and calculating the various environmental impacts of different materials using Environmental Product Declarations (EPD) and calculates the materials' initial phase of construction (i.e., until the material is on site). The students studied different wall structures and applied their knowledge of material type, dimension, and volume to the Construction Material Pyramid. The calculation focused on the used material amount in the wall of 3 feet wide per single floor to compare different buildings. In a brief period, students were able to compute several environmental impacts measurements such as Global Warming Potential (GWP), Ozone Depletion Potential (ODP), Photochemical Ozone Creation Potentials (POCP), Acidification Potential (AP), and Eutrophication Potential (EP) (e.g., Fig 2). A class discussion was dedicated to comparing the calculations and comprehending the disparities between collective assumptions and actual environmental impact.

GLOBAL WARMING POTENTIAL (GWP)							
NO.	MATERIAL	GROUP	IMPACT / m^2	VOLUME (m^3)	AREA (m^2)	Thickness (mm)	RESULT (kg CO2eq)
1	eucalyptus cover strip	wood/biobased	-1063	0.025	0.841	30	-26.6
2	eucalyptus boards	wood/biobased	-1063	.0.41	1.781	23	-43.6
3	eucalyptus battens	wood/biobased	-1063	0.012	0.384	32	-12.8
4	diffusion open membrane	plastics	266.3	0.002	1.781	1	0.5
5	mineral wool insulation	mineral/natural stone	70.4	0.178	1.781	100	12.5
6	timber beams	wood/biobased	-680	0.027	0.273	100	-18.4
7	concrete blockwork	mineral/natural stone	180	0.392	1.781	220	70.6
8	mineral wool insulation	mineral/natural stone	70.4	0.125	1.781	70	8.8
9	galvanized steel profiles	metal	22923.1	0.001	0.001	1	22.9
10	plasterboard	mineral/natural stone	169.6	0.046	1.781	26	7.8
11	double glazing	components	266.1	0.016	1.006	16	4.3
12	aluminum frame	components	11727	0.0004	0.001	1	0.5
13	beechwood window sill	components	474.1	0.026	0.026	40	11.4
14	HEB 220 steel girder	metal	8831.2	0.008	0.009	16	70.6
TOTAL			**41109.2**	**0.8974**	**13.227**	**676**	**108.5**

Figure 2: The Construction Material Pyramid. (CINARK 2023); and environmental impact calculation of Norvento Headquarters's wall using the Construction Material Pyramid. (Student: Libby Couture 2022)

2. CRAFT AS RESEARCH

Architecture students often perceive materials as codified products, relegating the creativity of material application to material specialists. In "Valuing Material Comprehension," James Carpenter challenges this notion by questioning the separation of materials knowledge from the design process. Carpenter notes that the term "craft" has acquired a negative connotation with architects since the Industrial Revolution (Carpenter 2010).

However, to break away from the confines of conventional practices, an understanding of craft and making is essential in fostering a learning culture that inspires students to challenge existing design tools and techniques, which may become irrelevant in the near future. This chapter introduces student research projects from each principle, highlighting the process of discovering constructability and navigating material constraints.

2.1 Assembly for Reuse

The demolition of buildings often results in the waste of materials that still have a lifespan longer than the building itself. The use of adhesives and fasteners, such as glue and screws, hinders the reuse of building components by permanently connecting them. The solution to this problem is to employ fastening methods that do not restrict future disassembly. The prototype study presented here implements straightforward and unobtrusive construction techniques that ensure the preservation of wall materials for easy reuse in future building projects.

The wall for this category was constructed using readily available and common materials such as 2x4 and 2x6 lumber wood, concrete masonry units (CMU), and ratchet straps for the column and beam structure. After thoroughly testing various binding methods for the wood members, the students ultimately selected ratchet straps for their strength and simplicity. The lumber wood was bundled together and secured with ratchet straps to form sturdy columns and beams, which were then sandwiched around the CMU with additional straps, which helped to stabilize with a minimal footprint (e.g., Fig 3).

Figure 3: Non-intrusive assembly connections using ratchet straps. (Author 2022)

This wall assembly system has been designed with versatility and practicality in mind. By utilizing the quick and non-invasive assembly method, it can be assembled with minimal labor and used as modular partitions in emergency shelters. The incorporation of insulation and cladding was investigated to augment the versatility of a modular divider. A multi-layered exterior, consisting of a thermal blanket, tarpaulin, and wire mesh, was suspended and clapped to the beam structure. The wire mesh layer provided a versatile surface for hanging multiple cladding options, and the students opted for a collection of gutter covers due to their affordability and the presence of holes that facilitated attachment to the mesh. The gutter covers were assembled with cable ties for seamless installation and disassembly.

The wall system is equipped with several essential features, including weatherproofing, soundproofing, insulation, and solar-powered lighting, making it a comprehensive solution for a range of temporary housing needs. By leveraging the benefits of this design, this construction method can provide quick and effective shelter solutions in times of emergency and crisis as well as easily used for other construction in a new condition. In order to embrace material circularity, the wall units were disassembled after installation and either rerouted back to the fabrication lab or donated to the local Habitat for Humanity, a philanthropic organization that supplies building material stores (e.g., Fig 4).

Figure 4: The assembled wall structure and their components after disassembly. (Author 2022)

2.2 Creative rreuse (upcycling)

One of the study areas focused on utilizing non-building materials to evaluate their feasibility. The course addressed the pressing issue of repurposing commonly discarded recycling materials in daily life, such as paper, paper, clothing, and aluminum. One student group delved into the innovative realm of plastic reuse in construction, with the aim of curbing the wastefulness of discarding materials into the recycling process, which demands a significant input of energy to purify, melt, and reduce plastic. Despite the generation of 51 million tons of plastic waste in the United States, a mere 5% was recycled (Greenpeace 2022). The low recycling rate can be attributed to numerous causes, including the non-recyclability of many plastic types and the environmental impact of recycling processes. Nevertheless, numerous examples of architecture have utilized plastic waste as building envelopes. For instance, architectural projects such as the Bima Microlibrary in Indonesia showcase an innovative solution through upcycling – a total of 1,872 ice cream buckets were transformed into an expressive facade and provided an ambient lighting environment within the interior space.

Students with an interest in utilizing plastic byproducts sought out readily accessible facade materials in their community that could provide shading and allow natural light to pass through. The primary focus of the research was the utilization of half-gallon milk jugs made of high-density polyethylene (HDPE). Students collected milk jugs from individual households and a local recycling center to test and build different prototypes. Being a thin and pliable plastic, HDPE offers a range of design possibilities beyond its original form. The plastic can be easily altered through cutting at various angles, leading to interesting formal manipulation and various openings. Six different cutting strategies were implemented by using three types of custom jigs, which allowed students to alter different brands and imperfect qualities of milk jugs into a consistent angle and dimensions (e.g., Fig 5). The different cut types create different possibilities of patterns, lighting, and visibility, such as opaque, translucent, and transparent conditions, functioning as a wall divider and veiled curtain at the same time.

The project developed into a lightweight wall partition that can be effortlessly suspended from any ceiling using cables and C-Clamps. The partition comprises a wooden modular frame that securely holds 60 milk jugs, which are held in place through a tension system woven with a fishing line through pre-punctured holes. The arrangement of the different cut types was carefully considered to determine the location of apertures, obstruct views, and create different lighting qualities. The final design was tested in a library setting, showcasing its ability to define space effectively (e.g., Fig 6). However, this versatile panel system can also be implemented in a range of interior settings, from large open areas such as offices or event spaces to create private areas.

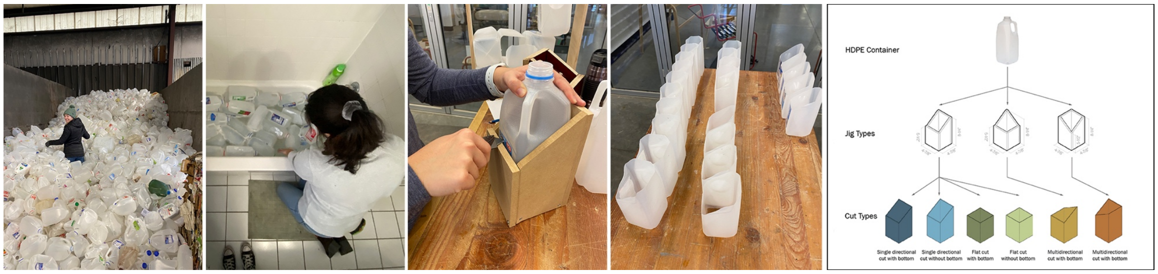

Figure 5: Process of plastic collection, sorting, washing, and fabrication. (Author 2022)


Figure 6: Reused plastic wall installation suspended under a library staircase. (Author 2022)

Another student group reenvisioned the use of fabric waste in the context of creative reuse in architecture, specifically as an alternative to traditional scaffolding and formwork materials made from steel and heavy-duty plastic. With over 60% of used clothing ending up in landfills, textile waste has become a pressing environmental issue. Inspired by the low-tech suspended fabric mold developed by Lilienthal in the late 19th century (e.g., Fig 7), the team sought to incorporate this principle into their design. The technique leverages the interplay between the self-weight of the casting mixture and the pattern of the clothing without the need for a negative mold. To bring this concept to life, the team decided to sew the clothing waste into a quilt which would then serve as a mold for concrete panels (e.g., Fig 7).

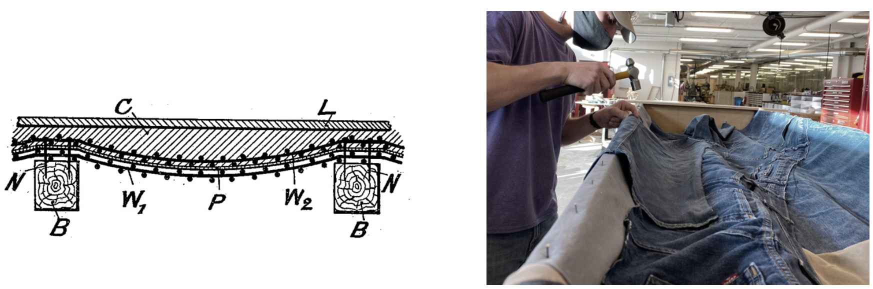

Figure 7: Fireproof ceiling patented by Lilienthal using hanging fabric mold (US Patent Office 1899); and fabric mold using clothing waste. (Author 2022)

The quilted formwork acted as a “skin” for each concrete panel, and the variability in the clothing types and patterns contributed to the distinct texture and form of the wall structure. For instance, shirts featuring vinyl heat transfer prints create a reflected image of the pattern in the concrete, while the thick, overlapping stitches on jeans create an imprint that clearly resembles pockets and belt loops. The variations in the elasticity of the materials result in an uneven thickness of the wall, imbuing it with a third-dimensional quality that is unattainable through conventional precast concrete methods (e.g., Fig 8). The panels can easily be fitted with apertures by incorporating sleeve and pant leg segments into the quilt, which protrude from the formwork.


Figure 8: Precast concrete panel from fabric waste formwork. (Author 2022)

2.3 Reclaimed building materials

There is a wealth of resources readily available in areas where projects are being demolished or materials are being discarded, such as factories or areas undergoing redevelopment. Reclaimed wood, versatile in its application, can be employed in a wide range of projects. Utilizing reclaimed wood offers a multitude of benefits for those seeking to use locally sourced materials, minimize transportation and processing costs, reduce carbon footprint, and incorporate a sustainable material while still enhancing the aesthetic quality.

The process of reclaiming and repurposing wood requires some effort prior to use. It is ideal for sourcing the wood before it reaches the landfill, and this can be achieved by searching demolition and renovation sites, shipyards, warehouses, etc. To classify the wood as high-quality reclaimed wood, it must undergo a series of processes, including the removal of nails and bolts, drying and stabilization, and smoothing of the rough exterior. If the wood is consistently sized, digital workflows can be utilized to input the measurements and determine potential design systems based on its shape and form, either parametrically or non-parametrically.

A team of two students delved into the exploration of using reclaimed wood to design a wooden facade for exterior screening (e.g., Fig 9). The reclaimed wood was sourced from torn-down barns situated within a 75-mile radius of the campus to reduce the carbon footprint in transport. The screening system was designed to offer versatility in regard to aperture adjustment, scalar growth, and density customization through the use of tensile connections. This facade system would be well-suited for a range of projects, particularly in the realm of adaptive reuse. For example, the tensile facade could be suspended from an existing building, adapting to its existing apertures, thereby providing the opportunity to alter the facade's appearance while preserving the existing building structure.


Figure 9: Wooden screen system using reclaimed wood. (Student: Anna Hartley and Jada Rezac 2022)

3. TOWARDS NEW MATERIALITY

3.1 Ecological tectonics

As Antoine Picon suggests, architecture is a supremely material art (Picon 2020). This simple definition raises the question of what artistic techniques are relevant in today's material world and how they impact the creative process, potentially leading to a transformative shift in our very perception of art. While architecture is a material practice, the continuous evolution of homogenized materials and techniques in architecture has diminished the prominence of materials, obscuring their inherent materiality. To overcome the reliance on carbon-intensive material products made from concrete, steel, and aluminum, the interrogation of a new family of materials with a comprehension of tectonics is imperative. The utilization of reusable materials can establish a sustainable cycle that embraces both the old and the new. As this paper highlights, reusable materials can take on various forms and serve a multitude of purposes, fostering material-focused construction and materiality stemming from material ethics and care.

For ecological tectonics to become widespread, a commitment and practice of understanding the material's technical characteristics, including its structural behavior, variable texture, and adaptability at multiple scales, is essential. Although some of the wall studies have unfinished qualities, they offer students insight into the continual latent tectonic possibilities. For instance, the fabric waste formwork can be explored further with alternative casting materials such as rammed earth and hempcrete, and by examining the rigidity, elasticity, and stitching pattern of clothing to achieve various geometric and structural capacities. Also, nonstandard forms and dimensions of reclaimed materials can be efficiently managed through computational methods such as 3D scanning and machine learning optimization. These inquiries can bridge the current disconnect between the potential risk of using new material pallets and current construction techniques. Ecological tectonics can also impart a clear narrative aspect to the wider audience, aligning with moralistic design intent and promoting openness and accountability in both the material management and execution phases.

3.2 Emerging resources

One of the biggest obstacles for circular construction is the procurement reutilization of materials and components and ensuring their accessibility. However, a number of entities and initiatives in Western Europe have set a commendable precedent by laying the groundwork for enhanced accessibility of reusable materials. For instance, Rotor Deconstruction[2] is an online inventory offering access to over 3,000 meticulously dismantled, cleaned, and cataloged salvaged building components such as furniture, lighting fixtures, doors, and tiles. This platform is designed to support building owners, contractors, and architects in their pursuit of second-hand materials. Similarly, Opalis[3] facilitates the identification of professional dealers, including private individuals or small contractors, of salvaged building materials, enabling users to locate sources based on the type of materials they need and their geographical location through mapping interface technology.

Furthermore, efforts have been initiated to provide technical support and foster computational advancements for improved digital evaluation, work processes, and tools for reclamation. For instance, Building Information Modeling (BIM) has been adopted in substantial development practices to examine materials in the recoverable dismantling of structures, such as the Aspern Seestadt in Vienna. Other endeavors, such as ReCapture[4], have embarked on utilizing drone and laser scanning technology to catalog building components and evaluate their suitability for reuse. As more resources and methods become accessible, they can be seamlessly incorporated into both the architectural profession and education.

3.3 Lessons and observations

The students were driven to engage in critical thought regarding contemporary building practices and material culture, with the potential to become practitioners in reducing environmental impact. The creation of full-scale prototypes transformed learning into a more inclusive and cooperative experience. Hence, architecture design education must consistently challenge itself to uncover novel prospects in sustainable materials and devise innovative ways to align building construction with more equitable outcomes.

The selection of materials holds significant importance as it imposes distinct limitations. The process of analyzing and cataloging reusable materials has proven to be both demanding and exhaustive, particularly in terms of locating suitable reclaimed wood with uniformity. Furthermore, the caliber of upcycled and salvaged materials cannot be compared to manufactured ones. When obtaining a substantial quantity of unconventional materials, it is crucial to take into account the imperfections arising from the recycling and deconstruction processes. A pedagogical setting may focus on hybrid construction techniques that blend unconventional and conventional materials to optimize time and labor, thereby examining the structural strength and pertinent details.

CONCLUSION

The concept of a circular economy is not novel, and environmentalists have espoused the reduce, reuse, and recycle ethos since the 1970s (Goldberg 2020). However, the recent prevalence of building technology and a machine-driven approach to construction has resulted in a narrow focus on the end product of architecture, neglecting the sourcing, transportation, and disposal of materials. Today, the pressing ecological and sustainability issues hold an urgent place for action in both building practices and architectural education. Overcoming our dependence on virgin materials and combating the perception of obsolescence is imperative. The utilization of obsolete materials creates a multitude of previously undiscovered challenges and impediments, which can only be conquered through persistent effort and hands-on experience. The educational setting and student projects highlighted in this paper demonstrate how architectural education is embracing the lifecycle of materials through a bottom-up design process that explores the constructability of reusing and repurposing materials. While these studies are in an imperfect state of progress, they raise important considerations regarding materiality and tectonics, uncovering the untapped potential of discarded materials to add depth and creativity to architectural designs.

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