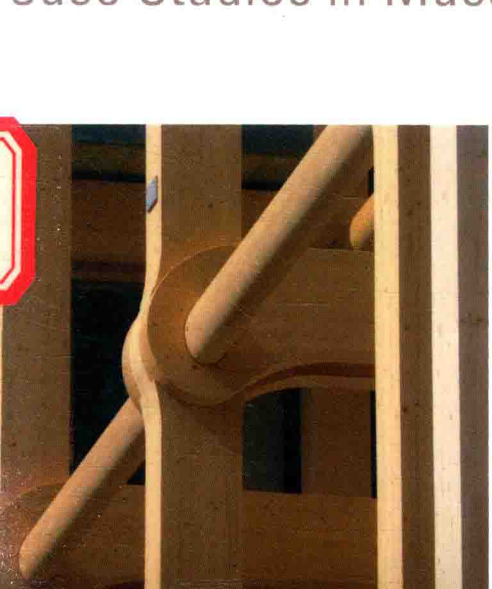
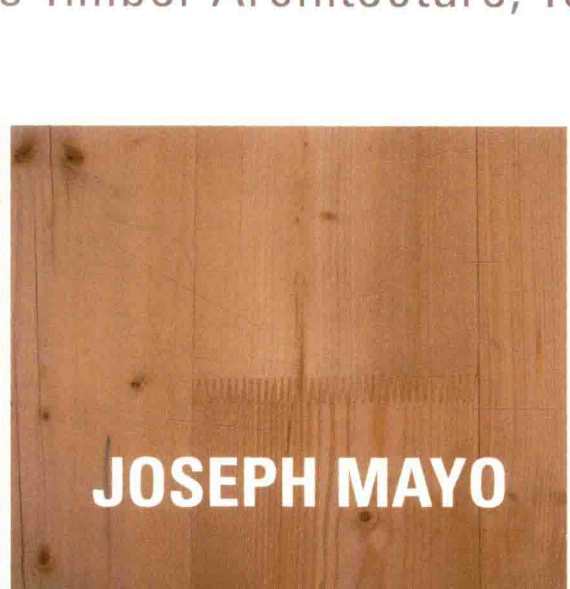
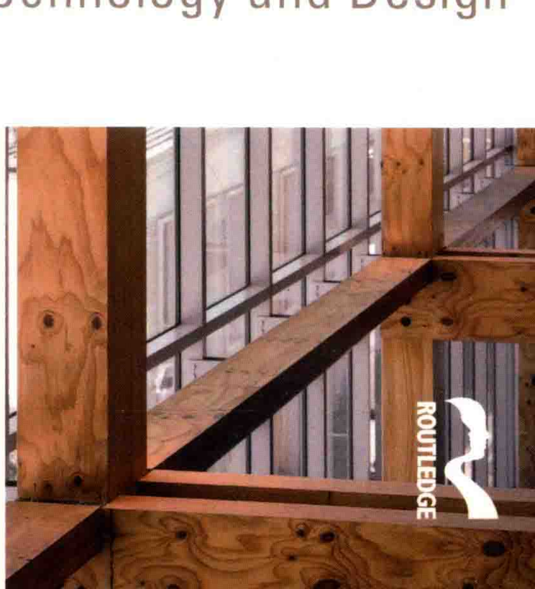
SOLID WOOD

Case Studies in Mass Timber Architecture, Technology and Design







JOSEPH MAYO

ROUTLEDGE

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Joseph Mayo

Routledge
Taylor & Francis Group
LONDON AND NEW YORK

First published 2015
by Routledge
2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN

and by Routledge
711 Third Avenue, New York, NY 10017

Routledge is an imprint of the Taylor & Francis Group, an informa business

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data
[CIP data]

ISBN: 978-0-415-72529-3 (hbk)
ISBN: 978-0-415-72530-9 (pbk)
ISBN: 978-1-315-74289-2 (ebk)

Typeset in Syntax 8.5/12.5 pt
by Fakenham Prepress Solutions, Fakenham, Norfolk NR21 8NN

Solid Wood

Over the past 10 to 15 years a renaissance in wood architecture has occurred with the development of new wood building systems and design strategies, elevating wood from a predominantly single-family residential idiom to a rival of concrete and steel construction for a variety of building types, including high rises. This new solid wood architecture offers unparalleled environmental as well as construction and aesthetic benefits, and is of growing importance for professionals and academics involved in green design.

Solid Wood provides the first detailed book which allows readers to understand new mass timber/massive wood architecture. It provides:

- historical context in wood architecture from around the world
- a strong environmental rationale for the use of wood in buildings
- recent developments in contemporary fire safety and structural issues
- insights into building code challenges
- detailed case studies of new large-scale wood building systems on a country-by-country basis.

Case studies from the UK, Norway, Sweden, Germany, Austria, Italy, Canada, the United States, New Zealand, and Australia highlight design strategies, construction details and unique cultural attitudes in wood design. The case studies include the most ambitious academic, hospitality, industrial, multi-family, and wood office buildings in the world.

With discussions from leading architectural, engineering, and material manufacturing firms in Europe, North America, and the South Pacific, *Solid Wood* disrupts preconceived notions and serves as an indispensable guide to 21st century wood architecture and its environmental and cultural benefits.

Joseph Mayo practices architecture in the Pacific Northwest where he concentrates on materiality, technology, and form for a regionally appropriate building culture. He has worked on a variety of building types, ranging from schools, student housing, university buildings, and hospitals. Working with a City of Seattle Department of Planning and Development (DPD) Advisory Committee, he led an investigation to use wood in applications that go beyond current building codes. He has also been a jury member for wood design awards, served as Regional Associate Director for the American Institute of Architects (AIA), Young Architect Forum (YAF) Chair at AIA Seattle, and has assisted in teaching courses and served on architecture critiques at universities around the Pacific Northwest.

Foreword: timber for the 21st century

We are faced with the two major issues in our time, man-made climate change and a soaring world population. To construct adequate housing for future generations we must reinvent construction so that we can fulfill this need with the minimum effect on our environment.

The construction of buildings across the world is dominated by concrete. We have been suffused by the stuff, producing billions of tons of concrete every year, building our cities our roads and bridges with it. But to manufacture just the cement that binds concrete is one of our most polluting processes, producing a tonne of carbon dioxide for every tonne of cement. We therefore have to reduce our reliance on cement and concrete in the construction of our buildings. It is simple yet imperative; we have to find a new way to build.

Timber was the first building material. Timber grows from the ground and is completely replenishable in a short time, whereas concrete and metal are limited materials which may one day disappear altogether. As timber grows it soaks up carbon dioxide through photosynthesis. The tree releases oxygen and stores carbon as it grows. This is surely what we have been looking for: a non-polluting, carbon-storing material that we can grow around the globe. Timber can help solve our global problems.

The rural idyll depicts Man's primitive hut, a rough timber structure—a basic shelter. We need to re-think this hackneyed view, timber may have been our first building material but it is not obsolete. Modern engineered timber is a sophisticated construction material and capable of immense structural feats—stronger than steel pound for pound. It is quick to construct, accurate and airtight. Timber is easy to fasten into, and easy to adapt. A timber environment has a natural humanity to it, you sleep better, and breathe better. The timber naturally regulates moisture and humidity, it gives a softer sound and calmer temperatures.

Before us then we have immense challenges in housing burgeoning urban populations and mitigating environmental disaster, but also fantastic opportunities. We have a new architecture to discover. What will these timber buildings look like, how will they shape the way we live and what kind of cities will we create? We are so steeped in conventional construction it is hard to imagine a future in a different direction. But this is the vision we need to build, a world where trees are valued and the timber that we harvest from managed forests is harnessed to create a new and sustainable future for humanity.

Andrew Waugh
Principal, Waugh Thistleton Architects
London, England

Preface

> Wood is the mother of matter … she renews herself by giving, gives herself by renewing. Wood is the bride of life in death, of death in life. She is the cool and shade and peace of the forest. She is the spark and ear, ember and dream of hearth. In death her ashes sweeten our bodies and purify our earth.
>
> —*Carl Andre, 1978*

Trees are omnipresent and nearly embedded into the DNA of everyone who calls Western Washington State home. Towering Douglas fir, Western Hemlock, Sitka Spruce, and Red Cedar, to name just a few of the species found there, define the landscape and capture the imagination. While conifers, some rising 100 m tall, delineate the landscape, timber once defined the architecture of this region as well, both urban and rural.

Wood is certainly still used for buildings in places like Seattle, where I live and work, but the use of large dimensioned timber is largely absent in contemporary buildings. However, there is a growing fascination among architects and designers with using large dimension timber elements—solid sawn and increasingly engineered solid wood/mass timber components—as a way to reconnect with the unique qualities of place and, somewhat paradoxically, to foster greater environmental stewardship. For these reasons and others, I believe mass timber construction has an important role to play in this century's increasingly urban landscapes.

Trees on the west coast of the United States can grow to skyscraper heights, and walking among these giants I have often wondered about the potential of wood in modern buildings. How large and tall could wood buildings become? Is it safe for large timber buildings to populate our towns and city centers as commercial, institutional, educational, and residential buildings? In 2011, with these questions in mind, I was awarded an Emerging Professionals Travel Scholarship from the Seattle chapter of the American Institute of Architects (AIA). With this grant, I was able to travel abroad, conduct site visits, and develop case studies on the emerging uses of wood in architecture. That fellowship was the starting point for this book.

Few books have addressed the use of wood in large, non-residential buildings. While light frame construction and residential resources are common, little has been said about the potential to utilize wood for taller, urban, commercial buildings. But a survey of new timber architecture around the world reveals this construction type's unique appeal and potential. Not surprisingly, enthusiasm for solid wood architecture and engineering is now growing rapidly among a new generation of architects and designers in part because wood construction materials use far less energy in production and when accounting for the carbon stored in their mass can actually be considered carbon negative.

Because there are regional variations in the use of wood in both historic and contemporary buildings, I have organized the case studies in this book by country rather than building type. I feel this creates a truer snapshot of the material and how it has been interpreted tectonically in different ways, grounded in time and place but also often hybridized in unique ways by international exchange. This book is meant to demonstrate the diversity of design options available using mass timber building techniques, whether that be panelized buildings, post and beam buildings, hybrid buildings, or modular buildings. While this book does not and cannot capture all of the innovation happening in timber buildings, it does present a cross-section of case studies that demonstrate how architects, engineers and designers are using novel approaches to challenge conventional notions about wood construction. In doing so, they are solving age-old problems of durability, stability and fire-safety while creating compelling, place-based architecture that can compete with more conventional materials. A desire to better understand the opportunity presented by solid or mass timber construction elements is the goal of this book.

A GLOBAL IMPERATIVE

Every year, billions of tons of carbon are released into the atmosphere from the burning of fossil fuels and the clearing of forests, creating a 40 percent spike in the concentration of atmospheric carbon since the beginning of the Industrial Revolution.[1] In 2012 carbon dioxide levels jumped to 395 parts per million and climbed to 399.71ppm in May 2013.[2] Scientists estimate that the last time the earth was this warm was the Pliocene epoch, between 3.2 million and 5 million years ago.[3] Increasing temperatures threaten higher seas, greater flooding, and more frequent and intense weather disasters such as droughts, heat waves, and forests fires.[4]

How could the innovative use of wood affect this current trajectory? Manufacturing and construction make up 13.8 percent of global CO_2 emissions.[5] In considering the materials used during construction, the highly energy-intensive production of iron and steel accounts for 30 percent of all industrial emissions, and cement accounts for 26 percent of all industrial emissions. The cement industry alone is estimated to use 2 percent of global primary energy consumption, or about 5 percent of total industrial energy consumption on the planet.[6] These high levels of energy use and industrial emissions can be reduced by the substitution of low-emission materials. Because wood sequesters far more carbon than is emitted during manufacture, the use of wood represents more than a 100 percent reduction in fossil fuel emissions compared to non-wood products.[7]

While cultures around the world have built with wood for centuries, recent advances in wood-based building materials and construction techniques offer for the first time a truly sustainable architecture that is just as applicable in urban environments as in rural settings. While high-emission materials like steel and concrete will continue to have a place in urban architecture, innovative, wood-based structural materials can be an essential part of building sustainable towns and cities. By sequestering carbon and storing it, wood construction disrupts the dangerous one-way flow of carbon dioxide directly into the atmosphere. No other structural building material can do the same.

Much can be said of the quantifiable environmental reasons to pursue wood construction, but this unique material also presents more subtle and qualitative arguments for its use. In the hewn logs, joinery, and ornament of traditional wood construction, we can find a reflection of the people and cultures who raised these structures. Often these buildings do not just resist external forces, but are meditations on life and the construction process itself.[8] The versatility of wood has allowed countless cultures to express their identity. While wood is a challenging medium to work with, its use can establish an identity of place and reclaim a heritage of building and craftsmanship. Today the use of wood is again capturing the imagination of designers and builders for many of the same reasons that our ancestors used this material: for its availability, versatility, and ability to renew itself.

NOTES

1 Gillis, J. (2011) "With Death of Forests, a Loss of Key Climate Protectors," *The New York Times*, 1 Oct., p. A1.

2 Vidal, J. (2013) "Large Rise in CO2 Emissions Sounds Climate Change Alarm," *The Guardian*, 8 March. Available from www.theguardian.com/environment/2013/mar/08/hawaii-climate-change-second-greatest-annual-rise-emissions.

3 Scripps Institution of Oceanography (2013) "Carbon Dioxide at Mauna Loa Observatory Reaches New Milestone: Tops 400 ppm." Available from https://scripps.ucsd.edu/news/7992.

4 Broder, J. and Gillis, J. (2012) "With Carbon Dioxide Emissions at Record High, Worries on How to Slow Warming," *The New York Times*, 2 Dec., p. A6.

5 Anderson, J., Fergusson, M. and Valsecchi, C. (2008) "An Overview of Global Greenhouse Gas Emissions and Emission

Reduction Scenarios for the Future," *European Parliament*, Policy Department Economic and Scientific Department, p. 13. Available from: www.ieep.eu/assets/428/overview_gge.pdf.

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8 Guidoni, E. (1975) *Primitive Architecture*, New York: Harry N. Abrams, p. 5.

Acknowledgments

This book could not have been possible without the generosity and commitment of many people who possess steadfast dedication to a different vision of building and sustainability. Throughout the process of gathering information and editing I was continually surprised and warmed by people's generosity and willingness to share and help. To these individuals I offer my deepest gratitude.

The project teams, educators and material manufacturers interviewed throughout the book (listed in the Appendix) offered an amazing wealth of material and often provided project documentation, illustrations, and photographs. In the case when photographs required purchase of image rights, I would like to thank the Forest Innovation and Investment Ltd. (FII) for providing funding to do so. Several professional photographers were generous enough to offer images for the book without charge, including Ioana Marinescu and David Grandorge. Eve Dennehy, Stefanie Esser, Susanne Höermann, Brad Kahn and Kris Spickler also helped provide additional high-quality photographs for use in the book.

I must also thank members of AIA Seattle who first helped me start the research for this book, including Lisa Richmond, Executive Director of the AIA Seattle and the Travel Scholarship Committee, including Dennis Haskell FAIA, Donald King FAIA, Flip Wood, Jim Suehiro FAIA, Rebecca G. Barnes FAIA, Peter Steinbrueck FAIA, and Susan Jones FAIA.

In addition to the professional design teams who helped review case study text, I would also like to specifically thank several professionals and academics for their generous help in additional review of the text: Kaarin Knudson, Hans-Erik Blomgren, Lisa Podesto, Jim Bowyer, Ethan Martin, Marjan Popovski, Christian Dagenais, Robert Gerard, Skip Kahane, Howard Davis, Kate Simonen, Andy Buchanan, Lin Hu, Arijit Sinha, Chris Duvall, Chris Knowles, Ermanno Acler, Bernd Gusinde, Nabih Tahan, Claes Caldenby, Christoph Loesch, and Dr. Ian Smith. I would also like to thank Jerry Yudelson, Daniel S. Friedman, Ryan Smith, Donald Corner, Pete Kobelt, Bruce R. Lippke, Elaine Oneil, and Erica Hildebrand for their help. Mahlum Architects offered generous time and support for me to conduct this research and complete the book. Finally, without the incredible help and support from my dad, Andy Mayo, this book could not have happened. Thank you!

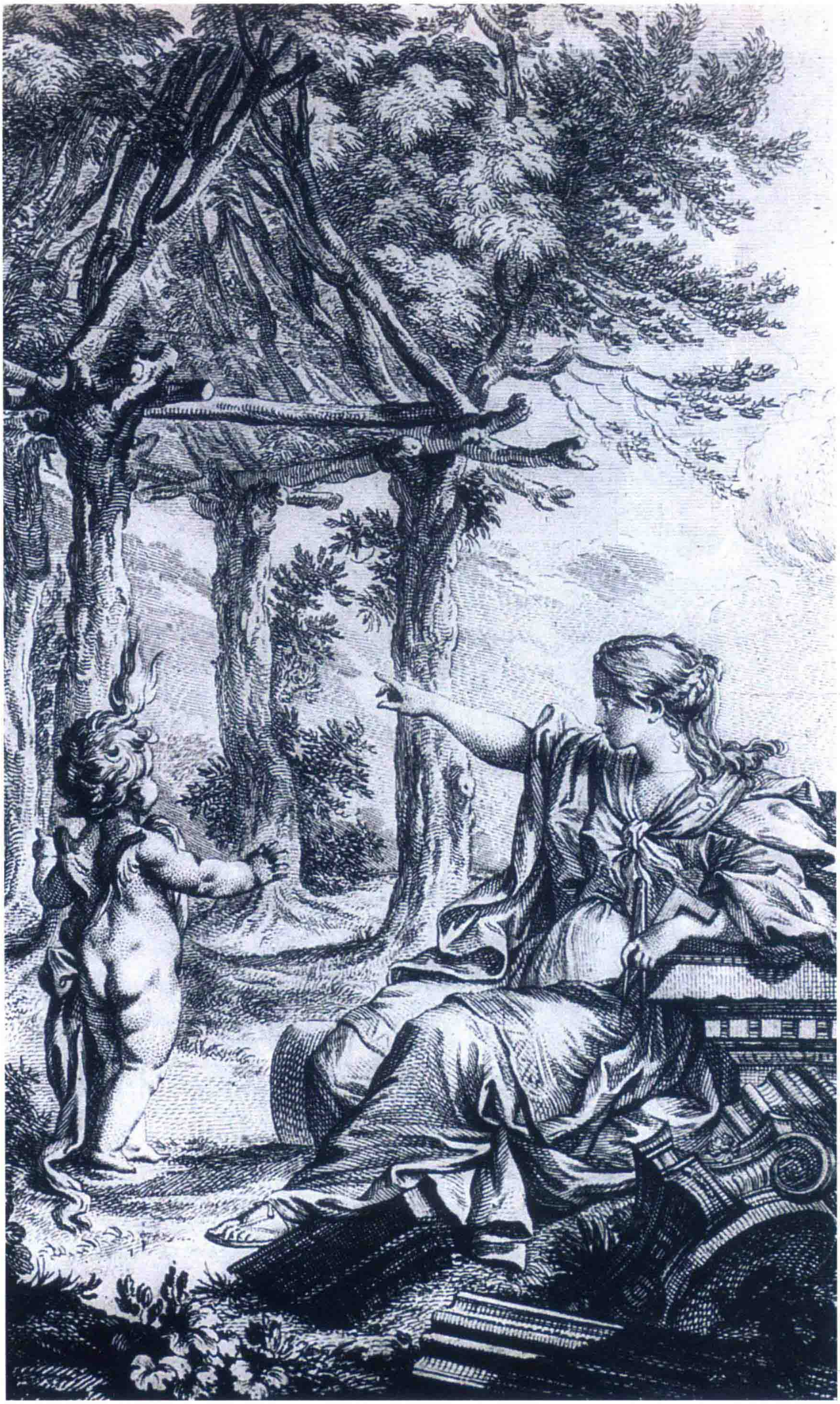
Joseph Mayo
Seattle, Washington, USA

A brief note about measurements and naming conventions:
Measurement units in this book are left in the method used in the country of origin, that is, native units. Most of the projects are found in countries that use the metric system (SI units) of measurements. While Canada officially uses SI units, some documentation uses either metric or imperial units. The United States uses only the imperial system of measurements. Consequently the book uses all three measurement methods depending on the country in which the project originated. For floor naming, the first floor of the building is the first upper level of the building, not the ground floor.

Contents

Part I

Building with wood



1.1.1 Illustration of primitive hut by French artist Charles Eisen appearing in Marc-Antoine Laugier's *Essai sur l'architecture*, 2nd edition from 1775

1 Introduction: a story of building with wood

The story of wood buildings is a tumultuous one. As a construction material, it has gone from near ubiquity to marginalization to a contemporary resurgence. Its versatility is unmatched: able to span large distances and create dizzying towers as well as humble homes and sheds. It can be used as structure, cladding, interior finish, and furniture alike. The warmth and patterning of its grain as well as its texture and aromatic scent affect us as few materials can. Wood is alive, which makes it special but also creates unique problems, from splitting and shrinkage to combustibility and rot. The material properties of wood spell out its story of failure and success.

Wood is among the oldest of all building materials, most likely predating even stone construction. Because wood decays, however, the historic role of this material in our world is more difficult to trace than stone and masonry construction. When nomads of the Stone Age could not find suitable shelter in caves, historians believe that they constructed tent-like huts from trees, branches, and twigs and covered the walls and roof with animal hides. For nomad hunter-gatherers, erecting these lightweight structures was surely preferred over strenuous and time-consuming stone wall construction. It was probably not until man settled from a nomadic lifestyle that more permanent housing and different forms of construction evolved. Archeological excavations in Holstein (northern Germany) dated from the twelfth millennium BC indicate circles of stone that may have been used to weight tent walls during reindeer hunts. This suggests man's first wood buildings. Similar buildings are thought to have existed in Neolithic Egypt as well. As nomadic people settled, the tradition of building wood tent structures evolved and took the form of more permanent wood frame buildings used by chieftains and kings.[1]

In Egypt, wood framing and solid mud brick construction developed side by side and led to some of the first examples of construction hybridization. From the dawn of historical time, Egyptians used wood frame construction with solid infill. Greek civilizations also used wood construction, with archeological evidence from Minoan and Mycenaean wood columns or combination of masonry walls and timber roof framing.[2] The first Doric columns in Greek architecture may have been constructed from wood, and several ancient buildings indicate, although contested, that the iconic Greek temple's origin is of wood not stone.[3] Parts of the Doric order found in classic temples, such as the triglyph, frieza, and architrave, are thought to be recreations of early wood construction tectonics.[4]

In the first century BC, Vitruvius placed the origin of architecture with trees and branches in the forest. Forests themselves create a type of architectural enclosure that has long inspired thinkers and designers. Spurred by new ideas from the Enlightenment starting in the 17th century, Marc-Antoine Laugier turned to the origins of architecture with his concept of the primitive hut: a dwelling constructed from four live trees with a simple roof of branches and leaves.[5] While not based on archeological evidence, the idea presents a primal intuition that wood and man have been intrinsically linked for millennia.

From Europe's northern boreal forests to more southerly deciduous forests, rich traditions in timber architecture have flourished. The Norwegians during their numerous Viking invasions are thought to have seen and copied their wood architecture from examples in Western Europe and translated it into stave churches, similar to wood construction developments in northern Russia. The alpine regions of Europe, because of their geography, developed heavy timber log structures, while inhabitants of central Europe preferred timber frame construction of oak with wattle and daub infill.[6] When Europeans immigrated to America, they brought traditional wood construction with them but adapted to their new environment. From its origins, wood architecture has been regional and highly place-based, emphasizing a region's particular character, creativity and unique way of engaging the land.

A CRAFT

Historically, our cities—especially in timbered regions and in places that could easily import timber—were built from wood. Before Europe's forests were logged, wood was accessible, plentiful, and nearly ready-made for structural applications. With builders passing down traditional knowledge and intuition of craft and carpentry, wood has long provided a type of local independence in construction. No other material offers the same ease of use coupled with strength and flexibility. Wood is light enough for large pieces to be lifted by hand, strong enough to support great weight, yet supple enough to easily carve for joinery or ornamentation.

While pre-industrial multi-family structures still stand, many wood buildings have endured for far longer. Built over 950 years ago, the 67 m tall Sakyamuni Pagoda in China is one of the tallest multi-story wood structures in the world. Constructed entirely from wood, the pagoda has survived an estimated 40 earthquakes without the use of steel or modern seismic bracing.[7] Many examples of ancient timber construction still stand today, testaments of the material's durability and longevity when cared for. Timber framed buildings were in fact the model on which subsequent steel and concrete construction was based.[8]

Prior to the 19th century, wood was the common building material in most of central and northern Europe and North America. Cities like London and New York contained as many wood or timber buildings as stone or masonry ones and the carpenter was the craftsman of highest standing in the building trade.[9] At this time, other cities such as Moscow, Tokyo, Bangkok, and Beijing actually contained far more wood buildings than masonry.[10] Hundreds of years of use had established a strong vernacular knowledge in the ways of building with wood.

Some of the earliest wood buildings drove posts directly into the ground for stabilization. Contact with the earth caused these structural elements to rot, and later the posts were lifted on to stone or masonry pedestals or set on sills to protect the structure from moisture and lengthen its life. Wood was often combined with other materials for infill or exterior walls. Wood joints, fastening, spanning, and building stabilization all advanced over time, creating more ambitious rural and urban buildings that rose taller in residences or spanned farther in great halls. It was common to see multi-story wood buildings in urban centers up to the end of the 19th century. In some cases these buildings rose six stories or higher.[11]

DECLINE

Quests for material permanence, taller heights, structural innovation, and new architectural styles conspired to stem advancements in wood craftsmanship during the last 200 years. Steel and concrete rose to new heights in European and North American cultural centers during the 19th and 20th centuries. Meanwhile, wood became associated with lower-grade and lower-cost construction—buildings of lesser stature, safety, and durability. There are several primary reasons for this rapid and remarkable change in our urban building culture.

The first major factor in wood's decline was extensive deforestation, particularly in western Europe where as much as 70 percent of the continent's original forests were converted to other uses.[12] Where forests once covered more than 90 percent of central Europe, by the 19th century this amount had shrunk to around 10 percent with old-growth forests essentially gone.[13] For some, contemporary discussions of wood construction still conjure images of ravaged forests and clear-cut land.

The second major factor in wood's decline was fire. Severe and often recurring fires in cities around the world created catastrophic destruction. The Chicago fire of 1871 killed hundreds, left 100,000 homeless and destroyed three square miles of the city. As a consequence, non-combustible materials such as brick and stone became the norm for urban construction and new regulations were often enacted to limit the use of wood in construction.

In addition to fire, the rise of industrialization and new construction methods using iron, steel, concrete, glass, and plastics eroded the use of wood. Many of these new products had properties that could be clearly verified and did not possesses the natural inconsistencies of solid sawn wood. Some scholars believe that Joseph Paxton's groundbreaking Crystal Palace erected for London's Great Exhibition in 1851 marked the turning point away from wood as a building material.[14] Made largely of glass and cast iron, and designed to showcase technological and industrial innovation, the Crystal Palace was nevertheless destroyed by fire in the early 20th century. The first steel skyscrapers, erected in US cities in the late 1800s, also pointed toward what would come to define the future of urban architecture.

Architectural doctrines like those promulgated in Le Corbusier's 1923 *Vers Une Architecture* called for a new modern and hygienic era of steel, glass, and concrete – an architecture founded on industrial mass-production and the machine. As "modern" architectural styles were promulgated and exported globally as an *International Style*, the use of wood, which thrives in place-based design, was further denuded. Along with the spread of these ideas across borders, advances in manufacturing and transportation opened new markets and cut off traditional building techniques and craftsmanship.

Following the world wars, with a need for fast and inexpensive housing to rebuild Europe, architects and builders turned to concrete and steel. Today these "modern" materials are ubiquitous and wood is often viewed as outdated and inadequate for commercial buildings. The widespread adoption of concrete and steel coupled with the enormous manufacturing infrastructure for these materials and building codes that now favored non-combustible construction led to their dominance, and a general lack of investigation of other materials.

A RESURGENCE

Today's interest in engineered wood buildings is driven by both technological advances and the growing concern for of ecology and sustainable construction practices. In many places, wood has caught up with concrete and steel in terms of industrialized manufacturing, prefabrication, and rapid site erection. In parts of Europe, according to the consulting engineer Josep Kolb, "the traditional carpentry shop has become a business with computer-assisted design processes and robotic controlled precision tools."[15] A growing group of architects and engineers from the sub-alpine regions of Austria, Germany, Switzerland, and Italy have adopted new wood building materials, connection systems, and fire protection techniques that have brought use of this material from an artisan craft to being part of modern practice. These alpine people, because of their challenging topography and limited natural resources, have established a self-dependency, resource efficiency, and durable craftsmanship in wood that is a model to follow. Designers and engineers from other regions have taken note and developed innovative timber buildings in their own right based on technology and resources available to them. With a new focus on high-tech production and speed, contemporary, engineered wood construction is able to compete with other materials on cost, but also offers the additional benefits of beauty, connection to craftsmanship, and a regional, ecologically-based architecture.

The reasons for wood's resurgence today are scientific rather than nostalgic, especially its environmental performance traits. Much international research has found that using wood in place of other construction materials can lead to a significant reduction in greenhouse gasses (GHG), while at the same time allowing for a net increase in the global forest cover if sustainable forestry practices are employed.[16]

SOLID WOOD AND WOODEN CITIES

After a century of decline, wood is findings its way back to the forefront of urban architecture. Cities are creative hubs where innovation, interaction, and discovery serve as the catalyst of change and progress. This kind of environment naturally fosters growth and creates the potential for a higher standard of living, as well as architectural innovation. Cities are also inherently more energy efficient than less dense communities. Urban dwellers require less heat in the winter, drive less, and require fewer miles of roads than their suburban counterparts. One study conducted at the University of California, Los Angeles found that a resident in Manhattan emits 14,127 fewer pounds of carbon dioxide per year than a suburban New Yorker.[17] If anywhere, it is in cities that we will find a sustainable way of living.

Using low embodied carbon materials for urban buildings can bring cities closer to goals of carbon neutrality. This is important because the UN estimates that by 2050 some 86 percent of the world's population will live in cities and population will have swelled an additional 2.3 billion.[18] To contain this kind of growth, planners and designers must build sustainably. Wood advocate and architect Michael Green, based in Vancouver, Canada, explains that with today's building culture, concrete will likely be used to house most of this growth, yet "concrete's large carbon footprint will continue to be a challenge without alternative structural solutions for the world's major environments."[19] Green goes on to say that "man can't compete with photosynthesis," meaning that materials generated naturally such as wood must be considered a real option to house future growth if we are to do this in a sustainable way.[20]

Recently, few countries have so intensely experimented with the use of solid wood in large institutional and multi-family residential applications as England. Alex de Rijke of London's architectural practice dRMM calls engineered wood "the new concrete" in a world of diminishing resources and growing environmental imperatives. He notes that:

> An abbreviated history of material technology as the main driver of architecture shows the best 17th century work to be characterized by stonework (e.g. Wren, Vanburgh, Hawksmoor), the 18C to be the refinement of brickwork (Georgian London & Dublin), the 19C to be the heyday of steel frame (Bessemer's mass production, Brunel's use of it), and the 20th century as the era of concrete (Nervi, Williams, Hadid). … This leaves the 21st century open for the successor to concrete. My prediction is timber.[21]

Whether de Rijke's prophecy will come true remains to be seen. But interest in solid wood construction has grown considerably among architects, engineers, universities, industry, and government during the past few decades, as the twin forces of technology and ecology drive the development of larger, taller, mass timber buildings.

NOTES

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2 Ibid., p. 14.
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4 Frampton, K. (2001) *Studies in Tectonic Culture: The Poetics of Construction in Nineteenth and Twentieth Century Architecture*, Cambridge, MA: MIT Press, pp. 4, 5–6.
5 Ibid., p. 31.
6 Herzog, T., Natterer, J., Schweitzer, R., Volz, M. and Winter, W. (2004) *Timber Construction Manual*, Basel: Birkhäuser, p. 28.