A Comparative Guide to

SUSTAINABLE CONSTRUCTION

for HOMEOWNERS and CONTRACTORS

Chris Magwood

MAKING BETTER BUILDINGS

BOOKS FOR WISER LIVING • MOTHER EARTH NEWS • RECOMMENDATION

Praise for

Making Better Buildings

Making Better Buildings is essential reading for home builders, owner-builders, or anyone interested in hiring a contractor to build their green dream home. This book is full of useful, up-to-date, cutting edge information and is amazingly thorough and easy to read. It will help readers make the best decisions possible regarding energy efficiency, cost, durability, health, embodied energy, labor requirements, and so on. Quite possibly the most valuable book ever published on green building!

— Dan Chiras, Ph.D., director, The Evergreen Institute (www.evergreeninstitute.org) and author, *The Natural House, The New Ecological Home* and *The Solar House*

Comparing contemporary building technologies based on criteria such as *embodied energy* or *energy efficiency* is a huge job — a job that holds most contractors and owner-builders back from making informed choices. Chris Magwood has saved us all thousands of research hours with *Making Better Buildings*. This book is not only a tool for the builders of today, but is a marvelous textbook for the young, emerging building professionals of tomorrow.

— Emily Niehaus, Founding Director of Community Rebuilds

At last: clarity! There are more and more people all over the world who are discovering the joy and satisfaction of building for themselves with natural materials. Very few, however, are also able to teach, communicate and inspire those around them. Of that precious few, Chris Magwood is at the top of the list; his delight and mastery of the subject hums in every page. Whether you want a broad overview, or access to high-quality, practical information on specific subjects, this is the book for you.

— Bruce King, PE, Director, Ecological Building Network

If you're drilling deep into sustainable building and want more than superficial details, let Chris Magwood be your guide. *Making Better Buildings* will help builders and homeowners quantify the green building process, and better understand the impact of their decisions.

— Scott Gibson, Green Building Advisor

Chris Magwood's new book is exciting news for builders and homeowners everywhere! This includes people who haven't even heard yet of the ideas that Chris lays out with such accessible knowledge and clarity. As one of the most knowledgeable and experienced ecological builders in North America, practicality and efficiency is one of his prime concerns. As one of the leading natural builders in the world, his affordable ideas are offered for all scales, within his broad and creative vision.

— Mark Lakeman, Communitecture Architecture & Planning, and cofounder,
The City Repair Project, Portland, OR

Based on Chris Magwood's considerable experience of sustainable buildings systems, this book provides invaluable guidance for builders, designers and those thinking of building their own home. Stripping away the hype, the book provides a rational and balanced assessment of alternative options for the major components of a building. It is particularly valuable since it includes a wide range of criteria such as cost, durability, code compliance and labour intensiveness together with environmental criteria, which make it a highly useful decision support tool for many sustainable building projects. Also, we are encouraged to get beyond the bickering about different systems at the "micro" level and to focus on the bigger picture, "macro" issues, when choosing building components and systems which will lead to significant change.

— Professor Mark Gorgolewski, Ryerson University

Making Better Buildings belongs in the library of every designer or builder in the green building business and should be read by every owner planning a new home. This is not simply green building — this is the future of construction! Chris Magwood has clearly described the pros and cons of the most viable natural building techniques and places them in context to create a tool that is timeless. All of the systems reviewed have the promise of significantly reducing the environmental footprint of construction.

— Jeff Ruppert, P.E., structural and civil engineer, and publisher, *The Last Straw Journal*

Ever wondered about the many shades of green in Green Building? The book you hold in your hand not only walks you through the vast array of techniques, written by one of the worlds most experienced green builders and educators, it also provides you with all the information necessary to compose the shade of green which suits you best. The information gathered here about issues such as techniques, embodied energy, health aspects are unique in the world, and is guaranteed to make this book the leading reference book for environmentally concerned building planners for years to come. Excellent work.

— Max Vittrup Jensen, consultant, and director, PermaLot Centre of Natural Building

We're often asked to recommend books to guide people along the path to building their own natural home. The list of books is quite short, but with *Making Better Buildings* it just got one important book longer.

— Oliver Swann, naturalhomes.org

This book is a must read for anyone trying to demystify the myriad of green building options. Chris Magwood packs this book with scientific data plus his unique hands-on experience. The result will leave every reader with a clear understanding of the benefits and challenges for a variety of super eco-friendly building methods."

— Sigi Koko, natural builder, and founder, Down to Earth Design www.buildnaturally.com

Chris Magwood offers a refreshingly objective analysis of technologies from foundations to finishes, informed by a very clear set of criteria that allows the designer or builder to compare and select the correct choice for their project. Where other books offer biased opinions, cursory overviews, or limited perspectives on building options, *Making Better Buildings* presents detail-rich, data-driven, experience-verified, field-tested solutions for every building component. This book is an invaluable resource for every building professional and motivated prospective owner seeking a trust-worthy source for information to help inform their practice. The name says it all!

—Jacob Deva Racusin, author, *The Natural Building Companion* and co-owner, New Frameworks Natural Building

Someday all buildings will be built sustainably; *Making Better Buildings* provides an expert compass for getting there. A must for any sustainable building library.

—Martin Hammer, architect, lead author of the Strawbale Construction appendix for the 2015 International Residential Code, and co-director, Builders Without Borders

It's a tall task to make the complex set of green building choices accessible and interesting – and Chris Magwood has done it well. As a teacher, and a systems and building consultant, I'd say this book ranks up there as one of the top three green building reference books. And it's the only one that covers the variety of building systems from foundation to roof so well, with enough building science, rationale and hints of philosophy to keep it beside your desk rather than the bookshelf.

—Gord Baird, Eco-Sense (ecosenseliving.wordpress.com)

If you're about to embark on building a new home, whether you're a professional or homeowner, this manual will help you discover the materials most suitable for your location and budget, and that do less damage to the environment than many standard materials.

—Cathy Rust, BE CGreen (becgreen.ca)

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new society PUBLISHERS

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This one's for Jen

Books for Wiser Living recommended by *Mother Earth News*

Today, more than ever before, our society is seeking ways to live more conscientiously. To help bring you the very best inspiration and information about greener, more sustainable lifestyles, *Mother Earth News* is recommending select books from New Society Publishers. For more than 30 years, *Mother Earth News* has been North America's "Original Guide to Living Wisely," creating books and magazines for people with a passion for self-reliance and a desire to live in harmony with nature. Across the countryside and in our cities, New Society Publishers and *Mother Earth News* are leading the way to a wiser, more sustainable world. For more information, please visit MotherEarthNews.com.

Contents

There is a basket of fresh bread on your head,
and yet you go door to door asking for crusts.

— Rumi

Thanks

This book wouldn't exist if not for all the amazing builders and designers who have spent lifetimes figuring out the best way to do so many different things. Some I've learned from through the amazing buildings they left behind. Some I've learned from through their books and articles. Others I've been lucky to meet and work with. The sustainable building community is amazingly supportive, collegial, open-source and adventurous. I am so lucky to be a part of it at this exciting time in its development. I hope you all see your names all over this work, even though I can't write them all down here!

I'd like to give personal thanks to:

- Jen Feigin, who never fails to show me that there's always a better way to do things, and a way to have fun doing it.
- Emma and Julie Bowen, who accompanied me as I started down this path and who made it possible for me to find my passion and pursue it.
- Sandy Zabludofsky and Gary Magwood, who always just go for it and work hard to make things work.
- Greg Magwood, for all the kung fu movies and a lifetime of companionship.
- Tina Therrien and Pete Mack, for making an adventure of making a living at making buildings.
- Barb Bolin and Ted Brandon, for bravely giving me the opportunity to teach other people how to make better buildings.
- Tom Rijven, for showing me that a good builder has good instincts, and trusts them.
- David Eisenberg, for being exactly the kind of role model I always seem to need.
- All the people who have participated in courses and workshops with me, because I've always learned as much from you as you have from me. It has been a privilege to make buildings with you all.
- All the clients who have trusted me to share their dreams (and budgets). It has been a privilege to do the work with you and then stand back and see you inhabit it.

Author's note

A house today is not what a house used to be. Our modern homes are no more similar to homes of the past than the modern automobile is to the horse. They may share the same purpose, but they achieve it in radically different ways.

A lot of advocates for sustainable building see a logical connection between the low-energy, locally sourced, affordable and sustainable homes of the past and their modern intent to make low-energy, locally-sourced, affordable and sustainable homes, and bemoan the fact that modern construction does not share these goals. This glorifying of the past is understandable, but the comparison is not realistic. Nobody used to the comforts of modern living would feel any glory whatsoever living in the conditions that even the best "non-modern" house would have offered its occupants.

The fact that we expect a higher degree of comfort than our "sustainable" forbears (who, like modern humans, were probably busy non-sustainably over-harvesting and over-using their natural resources; not many human societies have been "sustainable" in their activities) might cause us to conclude that there is no way we can maintain our current level of comfort in a sustainable way. The good news is this is not necessarily the case. What we've learned about making comfortable buildings in the last half century can be successfully married with what our ancestors learned about building with local, natural materials. Today, a smart, well-intentioned builder could make an amazingly efficient and comfortable modern building out of local materials as basic as earth, clay, timber, straw and stone. It would be as comfortable and "creature-friendly" as most modern homes (minus the overt luxuries), have a negligible energy and carbon footprint and maybe even be healthier to live in.

How we live in our homes has changed just as much as how we make them. Our expectation that a home is a place that does not need our engagement, attention, care, maintenance and love was not the case for our ancestors, and should not be the case in a sustainable world. In fact, a sustainable world is not possible unless we change this expectation.

To a large degree, it is only our unwillingness to give meaningful attention and care to our buildings that makes them unsustainable. It is possible to make a highly energy-efficient and comfortable building in a completely sustainable way if people are willing, able and interested in actively operating and maintaining their homes. A perfect example is the enormous difference between the environmental impacts of vinyl siding and a homemade earthen plaster. The practical difference for a homeowner is that vinyl will need no maintenance (unless it warps, cracks, gets struck and broken, fades, etc) for twentyish years, after which it must be replaced with all new material, while the earthen plaster will require a small amount of manual labor to apply a bit of the same earth from which it originated every five to ten years. Yet the vinyl has a

devastating ecological footprint, from the extraction of crude oil to the high levels of air and water pollution created at every stage of its production to the off-gassing that occurs over the material's lifetime to its disposal in a landfill at the end of that life span. The use of such products supports an economy and culture that is at odds with a healthy planet. The clay plaster has almost no impact on the planet.

The trade-offs in terms of our time and attention are surprisingly low, and may even come to be considered an improvement should we reach a day where we are no longer tied to full-time employment in order to make payments on a high-impact, "maintenance-free" house.

I became a sustainable builder not as a career decision but because I wanted a home my family and I could afford and live in comfortably without having to work full time to pay for it all. With many fewer helpful resources than exist today (no Internet!), a family of non-builders was able to design, construct, inhabit and love a home that had a radically lower impact on the planet than all its conventional counterparts. The "sacrifices" we made had nothing to do with our physical comfort but lots to do with things like washing dishes by hand, giving up the blow-dryer, cutting and splitting firewood, keeping track of water levels in a storage tank, not watching a lot of television and turning out lights in rooms when we weren't in them. Not dramatic sacrifices, but the results for the planet — and our family — were very dramatic.

Adjusting our expectations about maintenance and participation in the operation of our homes would make the job of making sustainable buildings entirely feasible today. Currently, the struggle for sustainable builders has little to do with actually making extremely sustainable and comfortable buildings, but convincing people that the small lifestyle changes required to inhabit such homes are worthwhile.

The building world is approaching very interesting times. The status quo is clearly no longer sustainable or feasible, but will we change our expectations of what a home is and can do for us, or will we pursue ever more expensive technologies that only a few can afford?

Human beings are extremely good at finding comfort in the face of any conditions. We are already capable of making functional, low- or no-energy homes with sustainable materials; imagine how much better we could make those homes once we set our minds to it. If the same amount of R&D went into making amazing human-powered tools and devices as goes into making the remarkable power tools and devices we currently use, we would quickly develop no-energy solutions that were affordable and easy to use; perhaps a single, bicycle-driven device that can pump large volumes of water, generate electricity and turn the laundry machine… maybe all at once! For a civilization that has figured out how to make automobiles and nuclear reactors, the hurdles to creating sustainable tools for creature comfort are not stumbling blocks. We just need to really want to get over them.

This book attempts to chart a path in a more sustainable direction, though that path has many variations. From its pages you should be able to select off-the-shelf building materials and solutions and make a home that is substantially more sustainable than current convention. You can also select materials and solutions to assemble your own comfortable, no-energy, lovely home, a home that will have negligible impacts on the environment, require no fossil fuel support and be healthy, beautiful and affordable. It doesn't matter which variation of this path you take; just heading in this direction is an important, life-changing and possibly society-changing decision. Congratulations for considering it, and I hope this book helps you find your own path to a more sustainable life.

Foreword

By David Eisenberg

Building books tend to represent a kind of snapshot in time. The constantly evolving nature of building materials, systems and technology, and the range of environments and designs in which they are used, makes a level of obsolescence a common fate for many such books. I know this well, having co-authored an early best-selling book on straw bale construction, now woefully out-of-date in many respects but still selling two decades later, mostly as an ebook.

Technical books can transcend this tendency. They can do so by presenting current, clear, relevant information coupled with the insight and understanding necessary to guide the reader in how to find, think about and apply the most up-to-date and specifically relevant information. The reader then can bring their own, now better-informed, judgment to bear on the decisions they have to make. Good technical books don't just provide information but ways of understanding relationships and information *in the context* of a given time, place and project.

This book, *Making Better Buildings,* makes an unusually valuable contribution to the process of actually making better buildings by doing just that. It makes available in straightforward language and usable form the type of information that people need to design and build more sustainable houses. There are no easy, pat answers to the questions about what is best, greenest, most sustainable, safest, etc … it *always* depends. It is an excellent guide for making better decisions based on a more comprehensive understanding of the particular things achieving your particular goals will depend upon.

To undertake the daunting and ambitious task of creating a book such as this, it would be a blessing for the author to have a healthy mixture of intelligence, curiosity, confidence, competence, actual experience, diligence, skepticism, humility and a good and durable sense of humor. Luckily for us all, Chris Magwood is just such a person.

The contents of this book are drawn from Chris's building experience and research, his observations and analyses and his willingness to openly explore possibilities with others pursuing better buildings. This includes what Chris has learned through leading and teaching the full design and construction process of actual high-performance buildings with ever-changing groups of students, year after year. Chris has thoughtfully woven this wealth of practical knowledge together with an honest and evenhanded presentation of pros and cons, knowns and unknowns and the views of supporters and critics for a wide range of the materials and systems with which more sustainable buildings can be built today.

A strength of this book is that it even enables the reader to make better decisions about topics it does not cover directly. Once informed by an underlying awareness of concerns, impacts, costs and benefits, and the upstream and downstream consequences of various choices, a person cannot help but begin

to see all materials, systems and processes in a new way. Lumber or steel or concrete or clay or bales of straw or plastic foam insulation cease to be just inert materials to be chosen strictly on the basis of their initial cost, availability or single-criteria performance factors, or their ability to gain easy code approval. Instead the building, and the whole design and building process, literally take on lives of their own. Considerations stretch far away from the building site to the origins and impacts of those materials, and across time through their whole life cycle in the building and beyond.

Yes, learning to consider all these things appears to make the process more challenging and complex, rather than simpler. But of course it has never been simple, and those approaches that seem to make it simple do so by masking important information from view during the decision-making process. This is mainly how we've created so many of the very problems that we are now trying to solve by building more sustainable buildings. Those of us who have embraced the reality that our choices and actions matter because of their unseen and unknown effects find personal value in aligning our way of working with our intention to design and build buildings that create the most good with the least harm over the longest time — not just for ourselves but also for future generations.

I've had the distinct pleasure of knowing Chris since September 2000, when we met at the Second Nebraska International Straw Bale Construction Conference. I have watched him grow into a leadership role, far beyond straw bale construction to natural building and on to teaching and writing and generously sharing what he is constantly learning. He is clearly an adherent of an old motto of mine — that the way to subvert the dominant paradigm is to have more fun than they do — and, especially, to make sure they know it.

— David Eisenberg

David Eisenberg co-founded and has led the nonprofit Development Center for Appropriate Technology (DCAT) since 1992. He has served two terms on the U.S. Green Building Council Board of Directors, founded and chaired the USGBC Code Committee for ten years, and served on the ICC committee that drafted the International Green Construction Code (IGCC). He has written for Building Safety Journal *(the magazine of the International Code Council), co-authored* The Straw Bale House*, and has published dozens of articles, forewords, book chapters and papers.*

Introduction: Thinking about sustainable building

There is a remarkable paradox when it comes to introducing new technologies, in construction or any other field. We expect new ideas or technologies to live up to unrealistically high standards, while at the same time we accept as normal many existing ideas or technologies that are inherently deeply flawed.

It is a commendable tendency to try to be "objective" about new ideas and weigh as much evidence as we have at hand in deciding whether or not we think they are worthy. But we tend to be much less than objective about the ideas and technologies we use on a daily basis. Because they are normal to us, we rarely examine them in any meaningful way. A certain degree of inevitability is attributed to the ideas we've normalized; we don't see them as choices in the same way we see new ideas as choices.

There are countless examples of this paradox in everything we do. In the building world, we find a great example in the use of milled lumber as our prime residential building material. Wood has every flaw imaginable for a building material. It burns; it rots; it's insect food; it warps, twists and cracks; it's a great medium for growing mold; its structural properties vary greatly by species, milling, drying and storing practices; it's often grown far from where it's needed; it's heavy; it's dimensionally unstable as climatic conditions change….

And yet it has come to serve us very well as a building material. We used a natural material that was available to us and figured out how to deal with all its "micro-flaws." In the end, we've normalized it and built an entire successful industry around an entirely flawed material! But if we introduce a new material that has even a small number of the flaws inherent in wood, we find ourselves up against naysayers who can only see the flaws and not the possibilities for being able to work with them.

There is no such thing as an idea or technology with no flaws. Recognizing this simple point is key to being able to consider new ideas fairly. There is an experiment I perform at public talks: I ask the audience how many of them have had to deal with a toilet backup at some point in their lives. The show of hands is almost guaranteed to be unanimous. Then I ask that same audience if they think the flush toilet is a bad, flawed idea that "doesn't work"; very few say Yes. And this despite having to regularly deal with some very unpleasant consequences due to an inherent flaw in the technology. We accept the micro-flaw of an occasional toilet backup as a reasonable trade-off for the convenience of using a flush toilet. However, I hear frequently that composting toilets "don't work" based on second-hand reports of a single incidence of the composter smelling or not composting properly. There's the paradox: the "normal" technology fails disgustingly at a rate of 100 percent, and yet the "alternative" is the one that gets branded as something that "doesn't work." In truth, both systems have some inherent flaws, and both will fail on occasion.

We've just learned to accept the micro-flaws of one and reject the micro-flaws of the other.

Every technology that we examine in this book has a number of micro-flaws, as do those conventional technologies they might replace. This book does not attempt to gloss over any micro-flaws. But the comparisons between sustainable technologies and their conventional counterparts do not and cannot stop at the level of micro-flaws. Sustainable building strives to address the larger and much more important macro-flaws in our approach to building.

It is at the macro level that all of the materials in this book have their advantages over conventional practices. To continue the comparison between flush toilets and composting toilets, we can see that both can be practically functional but also have some micro-flaws. On the macro level, however, the flush toilet is part of a system that sees billions of gallons of untreated or partially treated sewage enter our streams, rivers, lakes and oceans, while using vast amounts of clean potable water and a very expensive public infrastructure. Meanwhile, composting toilets can turn human "waste" into a valuable fertilizer with minimal infrastructure and little to no fresh water usage. It is at this macro level that we should be assessing our building technologies. In this case, the advantages of the composting toilet should be very clear.

If we can start making wise choices at the macro level, we can trust ourselves to figure out how to minimize the micro-flaws of any technology. We humans are incredibly good at refining ideas and techniques. Through repetition, we gain insights that allow us to make the process better and better each time we use it. We're good at doing things better, but we're not very good at doing better things. Doing better things means looking beyond the micro-flaws and basing our choices on minimizing impacts at the macro level.

One of the challenges in adopting any new technology is figuring out where we are on the learning curve, and at what point on that curve we feel comfortable jumping on board. Some of the systems presented here are quite well developed, with installation and maintenance instructions that are very complete and manufacturer and installer warranties that back them up. Others are relative newcomers (at least in the modern context) and the instruction manuals are literally being written and refined right now. We may not know the very best way to use some of these systems until a lot more early adopters have trial-and-errored their way to some kind of standardized practice.

This book is about making better buildings. Better buildings don't wreck the planet. Better buildings do not waste resources. Better buildings are healthy places for their occupants. Better buildings are better at the macro level. The micro stuff we will figure out, as we always have done.

How this book works

The past decade has seen an incredible shift in awareness about the environmental impacts of our built environment. The notion of building sustainably has moved from the rumblings and experimentation of a few fringe activists to a pervasive notion that has an entire industry questioning its priorities and methodologies.

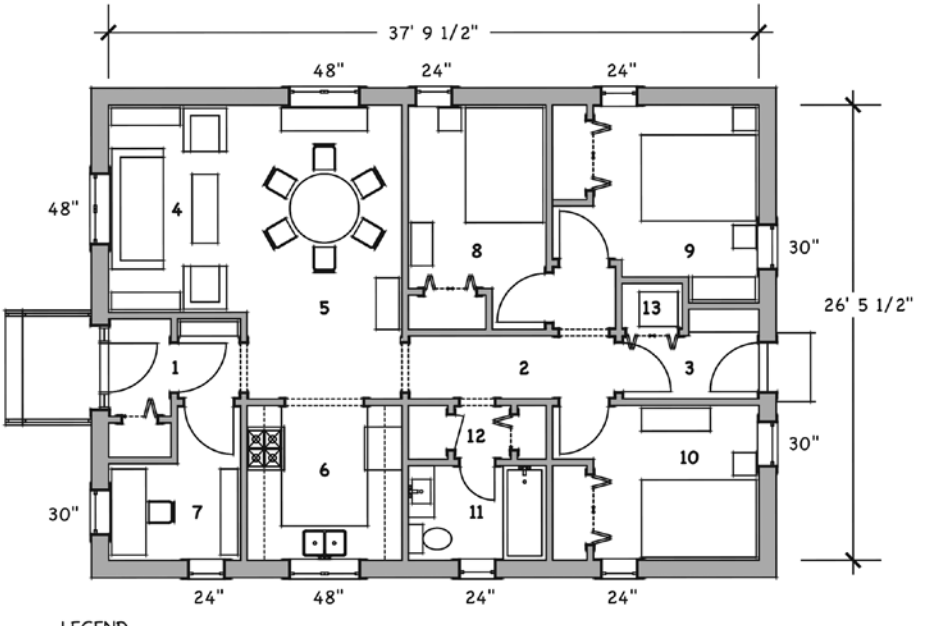
As the building industry reorganizes itself, the first round of changes we are witnessing is the "green building revolution." Green building brings a wide range of improvements to the ways in which we currently make our buildings. It is an important early step in changing a massive, multi-faceted industry, and the inroads made by green building advocates have already brought about remarkable changes in a very short time.

As huge a shift as the green building revolution continues to be, sustainable building activists are attempting to thoroughly reconsider and reinvent how we use materials and energy. The move to more realistically sustainable building will be as remarkable a change as the steel-and-concrete revolution of the early twentieth century.

In the twentieth century, cheap energy dramatically reorganized the building industry. For most of human history, manual labor had been used to convert local raw materials into buildings. The harvesting, processing and crafting of materials into buildings was done regionally, and it was the work of a great number of people in every city, town and village to provide these services. With cheap fossil fuel energy, the economic scale tipped radically in favor of mechanized processes. Materials are now harvested more intensively, transported to centralized factories to be processed, and then transported as building products to distributors, sub-distributors and retailers. Local trades purchase these products and assemble them into buildings using as little manual labor as possible. The occupants of buildings have become far removed from the process of designing and constructing, and therefore know little about what goes into making a building.

Cheap fossil fuel has enabled our society to build more, faster and bigger than anyone could have conceived a century ago. The merits of this growth are endlessly debatable, but we have collectively learned a lot about how to build quickly, efficiently and well. This book is written with the recognition that this era — with all its good and bad points — is coming to an end. The timing and nature of that end are also debatable, but what interests us is, what comes next?

There is no way to predict the direction any major revolution in ideas will take. There are, however, some visible signposts that can be followed in a direction that makes sense from our current vantage point. We aren't forecasting what kinds of new materials might be developed in the future—all of the building materials and systems covered in this book are being used to make buildings right now. Every material and system we examine is currently being



LEGEND

1 - Front Entry	50 SF	6 - Kitchen	81 SF	11- Bathroom	44 SF
2 - Hallways	60 SF	7 - Office/Den	55 SF	12- Linen&Mech	25 SF
3 - Rear Entry	35 SF	8 - Bedroom	104 SF	13- Laundry	10 SF
4 - Living	96 SF	9 - Bedroom	122 SF	**- Walls	55 SF
5 - Dining	153 SF	10- Bedroom	108 SF		

- All Doorways 34" Except: Bathroom 24"; Closets (Varies)

01/1000 1000 SF Prototype House
Floorplan - 1/8" = 1'-0"

used to make code-approved buildings that can meet modern standards of comfort, climate control and structural stability, yet with substantially lowered environmental impacts.

In this time of transition it can be difficult to assess new technologies and ideas, and that's where this book's approach attempts to be useful. We recognize that some of the systems examined in this book lend themselves very well to existing approaches to building and are only ever so slightly outside the mainstream. Others are much further from conventional approaches. We are not setting materials or systems against each other in a competitive manner; instead, we're attempting to objectively apply a well-rounded set of criteria to each one. Our criteria are:

Environmental impacts — What effects do the harvesting, manufacturing, transportation and use of this material have on our ecosystem?
Embodied energy — How much energy is required to harvest, process, transport and install this material?
Waste — What happens to the leftover material at the end of a project?
Energy efficiency — What impacts will the use of this material have on the energy efficiency of the finished building?
Material costs — What are the costs of acquiring and installing this material, based on current quotes for a sample home?
Labor input — How much labor is required to acquire and install this material based on current quotes for a sample home?
Ease of construction for homeowners — What level of skill is required for a homeowner to successfully install this material?
Sourcing/Availability — How widely available is this material, and where can it be obtained?
Durability — How long will this material last given appropriate conditions?
Code compliance — Is this material currently compliant with building code prescriptions and, if not, how is it treated/accepted as an alternative method?
Indoor air quality — What impact does the use of this material have on the indoor air quality in the finished building?
Future development — Does this material lend itself to significant improvements and therefore more widespread use in the near future?

All of these criteria are very important to a sustainable way of building, but not every one will have the same degree of importance for you as a designer, builder or homeowner.

There are no prescriptions, no "winners" in this book. In the end it will be up to you to weigh the information presented and make decisions according to your own needs. A builder looking for the lowest-cost options will find different answers than somebody looking for the highest indoor air quality or best energy efficiency.

Every building system summarized here is worthy of a book, and we point to those resources at the end of each section. There is no way to fully explain the intricacies and nuances of every system, and in attempting to summarize them we will certainly offend those who have devoted entire careers to a building method we explain and rate in just a few pages. Our intent is not to provide a "how-to" guide for any of these materials or systems, or a scientifically definitive rating. Instead we provide an attempt at an even-handed, objective comparison of the relative merits of systems that are all good choices. If there was a bad option, it wasn't included. If there were just one choice that trumped all others, we'd all be building that way. There isn't, and we don't. In the comparison charts, a low score is not a bad thing; it

just places that material/technology on a spectrum compared to other viable options. Compared to many conventional building options, these choices are all at the same positive end of the spectrum.

Where we use hard figures to quantify certain criteria, we are doing so based on a theoretical building, so that we are comparing identical scenarios across the board. Our theoretical building is a 1,000-square-foot (93-m3) bungalow with a simple hip roof, and the floor plans and elevation are presented. Obviously, your building project is unlikely to match this exact description, but the figures may be extrapolated and used as reasonable guidelines for your project.

This book can provide options, but it is up to each designer/builder to fully understand their own project goals. While this may seem obvious, it is surprising how often a building project moves forward without a comprehensive set of goals. Without well-defined and clearly stated goals it can be difficult to make the choices that face every builder. Why pick one design, material or system over another? Especially when sustainability is a priority, it is important to be clear about goals.

The list of criteria used to rate materials in this book represents a set of goals, and each builder must decide which of these ranks highest for a particular project. It's not enough to simply want "the best building possible." What will make it the best building for you? Designing a building means making compromises between competing factors. You are unlikely to create the most energy-efficient, least environmentally impactful, cheapest, easiest, fastest, most durable, most code-compliant, most recyclable building with the highest possible indoor air quality. You will be able to do reasonably well in some of these aspects, and very well in others. It's best to know in advance which ones you prioritize, and why. Making a building is a time-, resource- and finance-intensive endeavor; you'll want to complete it with the fewest regrets and mistakes possible, and the only way to do that is to start with clear goals.

This book recognizes the extraordinary number of decisions that must be made when planning to build sustainably, and aims to help you with those choices. There is no one way to build sustainably, and it's our hope that the information presented here allows you to bring your needs, climatic conditions, skills and environmental commitment together to make a better building.

Resources for alternative and natural building

Racusin, Jacob Deva, and Ace McArleton. *The Natural Building Companion: A Comprehensive Guide to Integrative Design and Construction.* White River Junction, VT: Chelsea Green, 2012. Print.

Nunan, Jon. *The Complete Guide to Alternative Home Building Materials & Methods: Including Sod, Compressed Earth, Plaster, Straw, Beer Cans, Bottles, Cordwood, and Many Other Low-Cost Materials.* Ocala, FL: Atlantic, 2010. Print.

Kennedy, Joseph F. *The Art of Natural Building: Design, Construction, Resources.* Gabriola Island, BC: New Society, 2002. Print.

Elizabeth, Lynne, and Cassandra Adams. *Alternative Construction: Contemporary Natural Building Methods.* New York: Wiley, 2000. Print.

Chiras, Daniel D. *The Natural House: A Complete Guide to Healthy, Energy-Efficient, Environmental Homes.* White River Junction, VT: Chelsea Green, 2000. Print.

Pearson, David. *The Natural House Book: Creating a Healthy, Harmonious, and Ecologically Sound Home Environment.* New York: Simon & Schuster, 1989. Print.

Woolley, Tom. *Natural Building: A Guide to Materials and Techniques.* Ramsbury: Crowood, 2006. Print.

Snell, Clarke. *The Good House Book: A Common-Sense Guide to Alternative Homebuilding.* New York: Lark, 2004. Print.

Snell, Clarke, and Tim Callahan. *Building Green: A Complete How-To Guide to Alternative Building Methods: Earth Plaster, Straw Bale, Cordwood, Cob, Living Roofs.* New York: Lark, 2005. Print.

Chiras, Daniel D. *The New Ecological Home: The Complete Guide to Green Building Options.* White River Junction, VT: Chelsea Green, 2004. Print.




1

Foundations

A building's foundation is extremely important to its longevity and performance. As such, it is often the one element where homeowners and builders will tend to choose the "tried and true" techniques and avoid "experimentation."

This is unfortunate, because the "tried and true" methods and materials typically involve the highest environmental impacts and often the lowest energy efficiency. Most North American homes use vast amounts of concrete in their foundations, and concrete is a perfect example of the kind of energy-intensive building material that has led us to our current environmental state. The production of the portland cement that is the "glue" in concrete requires using large quantities of fuel to heat limestone to very high temperatures to change its chemical composition. In the process the carbon dioxide trapped in the stone is released into the atmosphere (along with additional CO_2 released by the fuel used to heat the rock). Cement manufacture is one of the world's leading sources of greenhouse gas emissions.

Widespread and prodigious use of concrete is only possible when vast amounts of cheap energy can be used to quarry, heat, process and transport the material. Every rise in energy costs will be reflected in a rise in concrete costs. Where once this material was the cheap, obvious answer when building foundations, it is becoming less so all the time.

In the attempt to make concrete foundations more energy efficient, concrete is often combined with foam insulations. These insulations also have dramatic environmental impacts. If we can eliminate concrete use in foundations, we also tend to eliminate foams (though not always). In the following discussions about more sustainable foundation materials, careful thought must also be applied to the insulating of these foundations, and insulation options will be addressed for each system examined.

In considering more sustainable foundation systems, a builder is forced to consider a number of challenges to typical expectations. In much of North America, foundations have been twinned with conditioned, subgrade living space: the basement. In many markets, having a basement is so normal that it can be hard to convince a homeowner to imagine a house without one. It is difficult to create a sustainable basement and — unless the home is in the driest, best draining of soils — impossible to create a basement that doesn't rely on several layers of petrochemical products to stay dry.

As you will see in this section, there are many ways to create stable, long-lasting foundations that

have reasonable environmental impacts. Most of them, however, do not make basement foundations and those that do come with significant labor requirements. The fact of the matter is that building large, conditioned basements has been a privilege of having cheap energy at our disposal. We are nearing the end of commanding that privilege.

There is one great benefit to moving away from conditioned basement foundations: cost. The cost savings that can be realized by using a sustainable, grade-based foundation are substantial, and can be used to lower the price of the entire project or traded off against sustainable materials or systems that would otherwise drive up the overall cost. It is possible to build with higher-cost renewable energy systems at a competitive cost due to savings on the foundation.

There is no doubt that the most skepticism and wariness about sustainable technologies will happen here, at the foundation. As with any change, the underlying assumption — the "foundation" — is the hardest to change. Yet this is the place that most needs changing.

Building science basics for foundations

A foundation transfers loads from the building to the ground and anchors the building to the ground. To adequately perform this role, a foundation must have enough compressive and shear strength to handle all gravity loads (the weight of roof, walls, floors) and imposed loads (occupants, furniture, snow, rain, wind, earthquakes) placed on the building and prevent the building from moving on the ground.

In areas with cold climates, the foundation must provide stability even when frost has penetrated the soil surrounding the building. When soils containing water freeze, they can expand up to 10 percent in volume and exert pressures upward of 100,000 pounds per square inch, enough to lift or shift a building. When frozen soils thaw, they can become supersaturated with water, resulting in dramatically reduced bearing capacity, enough to cause a building to sink. There are two basic strategies for achieving frost protection for a foundation:

Footings below frost depth. This strategy involves digging into undisturbed soil to a depth lower than the expected frost depth. Building codes will prescribe frost depths regionally. The foundation then becomes a wall that rests on this sub-frost footing and extends to a suitable height above grade to start the floor/walls of the building. *Frost walls, basements* and *piers* fall into this category.

Shallow, frost-protected foundations. This strategy involves installing an insulation blanket horizontally around the perimeter of the building to prevent frost from entering the soil beneath the footings. The footing can be at grade or just below grade, minimizing the amount of excavation and material required to build the foundation. *Grade beams* and *slabs* fall into this category.

Many of the materials examined in this chapter can be used for either kind of foundation, but some can only be used for one or the other.

The foundation also separates the building from the ground, and this separation must include keeping ground moisture from rising into the building and surface moisture from getting into or under the building.

The foundation must also keep out insects, rodents and other unwanted guests trying to enter the walls or the living space. These pests will vary by region, as will the strategies for keeping them out.

A foundation can play an important role in the energy efficiency of the building. A properly insulated foundation thermally protects all edges of

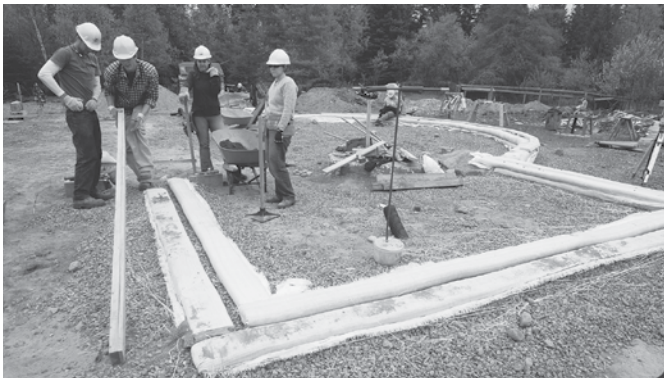
the building. Where floors and/or walls attach to the foundation, preventing thermal bridging and unwanted air movement is particularly important. Strategies for achieving a well-sealed, well-insulated foundation will change depending on materials used and climatic conditions. Don't fall prey to the common mistake of assuming that "heat rises" and therefore it's not important to insulate around and under foundations. Heated air rises, it's true, but heat energy moves effectively in any direction by radiation and conduction. A warm building in contact with colder soils will continuously transfer heat to the ground, which has an almost infinite capacity to absorb that heat. If you don't want to attempt to heat the entire mass of the Earth's crust, insulate your foundation adequately!

Durability is of exceptional importance when it comes to foundations. All the other components of a building can be repaired, restored or replaced as they age. Foundations can also be fixed, but it's rarely easy and usually expensive to do so. If a foundation has a short life span, the building above it is usually condemned to the same short life span. All of the various building science aspects of the foundation will have an impact on its life span, as will the nature of the materials used.

No foundation can be considered sustainable unless it combines adequate strategies for meeting all of these building science objectives and does so with materials that can last a long time in a demanding environment.

Earthbag (or flexible form rammed earth) foundations

What the cheerleaders say...	*What the detractors say...*
Extremely low environmental impact	Bags won't last
Widely available materials	Too labor intensive
Simple technology, simple tools	Foundation will be leaky
Excellent thermal mass	Low energy performance



Earthbag foundation. (David Elfstrom)

Applications for this foundation system

- Perimeter beams
- Frost walls, including full basement walls
- Piers
- *Can also be used as exterior and interior walls above grade*

Basic materials

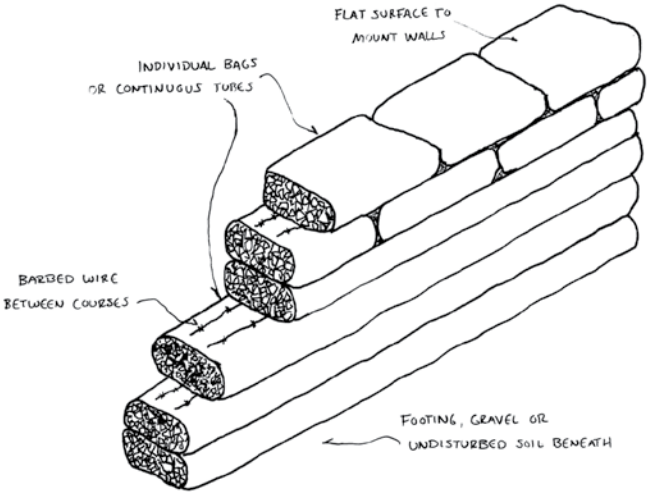
- Woven polypropylene bags (grain or feed bags) or continuous polypropylene tubing
- Soil, typically from site excavation, containing a good mix of gravel, sand, clay and silt
- Amendments for soil mixture, if necessary. Can be graded gravel, sand, road base, portland cement, hydrated or hydraulic lime, blast furnace slag or fly ash

- Barbed wire
- Tampers, manual and/or mechanical
- Many different bag stands or chutes have been custom made to facilitate the bag loading process. None are commercially available, but most can be made quickly and easily with available materials.

How the system works

The more descriptive term for earthbag construction is "flexible form rammed earth," which gives a more accurate impression of how the system works. Woven polypropylene bags or continuous tubes are filled with a gravel-based mixture that will tamp well and solidly. As the mixture in the bag is tamped, it flattens until the bag reaches its maximum stretch, at which point it firmly contains the material and allows for tamping to a high density. The bags or tubes can be laid out in straight lines, using string lines, but can also conform to any building shape.

The fill material that is rammed in the earthbags varies widely by region, builder and code/engineering requirements. A high proportion of aggregate is always used, with the binders ranging from indigenous clay soil to hydraulic agents like hydraulic lime, fly ash, blast furnace slag or portland cement. The compacted mix creates a stable long-lasting mass that does not rely on the bag for containment once it has been compressed and cured or dried to full strength.



Earthbag foundations can be made with fill mixes that rely on the bags for long-term containment of the materials, usually graded gravel or, less frequently, sand. The bags have a long life span when buried, and backfill around them will both protect the bags from degrading in sunlight and provide additional restraint for the materials should the bags fail.

The bags and tubing come in a wide range of widths, from 9–24 inches (230–600 mm), so a foundation can be designed according to the stability and strength requirements of any building. A double wythe system can also be designed, using two rows of narrow bags to create an inner and outer foundation wall for wide wall systems and to allow for internal insulation strategies.

The construction methodology is the same regardless of bag size or fill type. The mix is created, moistened to the correct degree and placed into the bag or tube. When the bag contains the correct amount of mix it is tamped vigorously, manually or mechanically. The tamping process subjects the mix to a force greater than the force that will be placed on the foundation by the building loads.

The foundation wall is built up in a number of courses. The thickness of each course depends on bag size, amount of fill and degree of compaction. Typical earthbag courses range from 4–8 inches (100–200 mm) in thickness.

Between each course of earthbag, a strand or two of barbed wire is typically used to prevent the bags from sliding on top of one another in any direction. Multi-pointed wire (three or preferably four barbs) ensures that every knot is making good contact with both bags. The wire is treated like rebar in concrete, with continuous corners and overlapped joints.

Walls will sometimes be installed directly on the earthbag (with a suitable moisture break), or wooden sill plates or a thin concrete beam can be used.

With practice, an experienced crew can build courses of earthbag quite quickly and with a high degree of level and plumbness and a consistent compaction.

Tips for a successful earthbag foundation

1. Placement of materials to be mixed should facilitate easy delivery to all points of the foundation.
2. Don't lay string lines directly on the foundation lines, as the bags will nudge the string constantly. Instead, lay out lines that are a couple inches wider than the foundation and measure into the bags.
3. A sturdy loading stand will make the job much faster. The resources listed below describe various loading stand options.
4. A practiced team can move quickly and create a very level surface. As you are learning, don't worry about every course being perfectly level. In the end, only the top course matters and you can make corrections on successive courses. A transit or laser level makes the job much more accurate.
5. Fill a sample bag to determine the height of each course to plan the number of courses and quantity of bag material required.
6. Secure the bag material well in advance to ensure supply and sizing.

Pros and cons

Environmental impacts: *Low*

Bags:

Harvesting — *High.* Polypropylene (PP) is a resin of the polyolefin family derived from crude oil and natural gas. Impacts include significant habitat destruction and air and water pollution.

Manufacturing — *Moderate to High.* Polypropylene is among the least energy-intensive plastics to manufacture, and a growing percentage of PP is derived from recycled sources. Impacts include significant air and water pollution. Weaving PP strands into bags is a moderately intensive mechanical process with no significant impacts.

Transportation — *Moderate.* Sample house uses 26.25 kg of bag material:

0.04 MJ per km by 15 ton truck
0.025 MJ per km by 35 ton truck
0.0065 MJ per km by rail
0.0042 MJ per km by ocean freighter

The majority of bag production is in Asia, ensuring that most bags used in North America have relatively high transportation distances. Quantity of material required is low, mitigating impacts.

Installation — *Negligible.*

Fill:

Harvesting — *Negligible to High.* Site soil fill will have negligible impacts.

Aggregate and virgin hydraulic binders (if required) are mechanically extracted from quarries and can have low to high impacts on habitat and ground and surface water contamination and flow.

Manufacturing — *Negligible to High.* Site soil fill will have negligible impacts.

Aggregate is mechanically crushed and has moderate impacts for fuel use for machinery and dust dispersion.

Virgin hydraulic binders like lime and portland cement are fired at extremely high temperatures and have high impacts, including fossil fuel use, air and water pollution and greenhouse gas emissions.

Recycled hydraulic binders like fly ash and blast furnace slag are the by-products of industrial processes that have high impacts, but these can be mitigated