Chapter 1

Introduction

Straw bale building has made remarkable inroads since the resurgence of this American pioneer building method in the 1990s. From just a handful of enthusiastic builders in the southwestern United States, the use of straw bale walls to make healthy, energy-efficient and low-impact homes and commercial buildings has grown exponentially in only 20 years, and is now recognized in *Appendix S* of the *2015 International Residential Code (IRC)* in the United States. Professional builders, guilds and organizations around the world are actively building and developing methodologies for meeting code requirements while honoring the environmental impetus that inspired the straw bale pioneers.

A Grassroots Development

In a building industry in which innovation and code change are predominantly driven by patents and corporate financial interests, the fact that straw bale building has grown so quickly and widely within a code-driven context speaks volumes about the inherent applicability of this style of construction to a wide range of climates and building contexts. Those pushing straw bale building forward have done so with only grassroots means at hand; there have been no well-connected lobbyists or industry reps involved, no reliable sources of funding, only individual designers and builders with a passion for the advantages this building style can offer individuals and society at large.

The labor equation

The major hurdle that straw bale building faces in its move toward widespread adoption is the higher labor inputs that site-built straw bale walls require. On a construction-cost basis, it has been adequately demonstrated that a well-trained straw bale building crew can complete homes at a price point that is entirely competitive with conventional approaches, as lower material costs can be leveraged to offset higher labor costs. But the conventional construction industry prioritizes the reduction of on-site labor inputs, even when the cost advantages of labor-saving materials and systems are negligible — or even more expensive. The ability to shorten the build cycle and minimize the time construction crews need to be on site motivates the industry. And if the additional labor time involved in straw bale building and the attendant increase in the length of time that crews are on site are not deterrent enough for mainstream contractors, then the need to train crews to work with a new material, using new techniques and methodologies, are certainly barriers to bale walls becoming part of the mainstream palette of options.

An innovation is born, accidentally

Many straw bale builders have recognized this "deficiency" and have put their minds to exploring ways to get past this hurdle. My own foray into prefabricating straw bale walls began in 2000, when I was invited to create a display for the Toronto Home Show. Realizing it would be impossible to site-build a model straw bale home within the window of time allowed by the show, my partners and I decided to build and plaster the walls in my barn, and deliver the finished panels to the show floor for assembly. We

had no idea if it would work, but went ahead and gave it a try. The panels arrived at their destination in perfect condition — no plaster cracks or other transportation issues, and one panel even survived a forklift mishap that saw it fall to the floor but sustain almost no damage. The demo building was assembled very quickly, and I can still feel the "high" that came along with watching this crazy idea prove itself to be extremely feasible.

In the following 15 years, I've been fortunate to have had the opportunity to build a large number of buildings using prefabricated straw bale panels. Each outing has involved changes to the construction, the lifting and assembling process and the final finishing of the panels. While I cannot say that the process is perfected, I can definitely say that every option we've used has been viable and a vast improvement on the labor input and construction timeline of site-built straw bale walls.

An international phenomenon

At the same time that I began experimenting with prefab bale walls, the idea surfaced in no fewer than three countries on three different continents, without any direct contact between those trying out the system. Within a few years, there would be early adopters in at least half a dozen more countries. Today, there are several commercial ventures producing panels and a number of builders who use the technique on a regular basis.

A long list of advantages

The benefits of prefabricating straw bale walls are many, and include significant reduction of labor input (especially plastering labor); removal of weather restraints during construction; better curing conditions for plaster; more consistent wall construction and plaster thickness; greatly

The first set of prefab bale panels were used to build a small demonstration home in Toronto in 2000.

shortened installation time; and a straighter, squarer and more conventional aesthetic. All of these help to position this type of straw bale building as a real alternative for conventional contractors. A contractor can order walls and have them installed without needing to engage with new supply chains or teach crews new skills. There are no truckloads of bales to be brought to construction sites and stored, no messy on-site plastering. The walls arrive and go up, and within a day or two the wall phase of the building is done and the crew can move on to roof framing, with the structure, insulation, air sealing and sometimes even the final finish of the walls completed in a single step.

Prefab doesn't preclude site building

Some straw bale builders see the use of panelized systems as being antithetical to the grassroots nature of straw bale construction. But there is no inherent either/or choice to be made. Those who have a passion for building with bales on site and hand plastering the walls *in situ* have many excellent reasons to continue to do so. Panelized systems don't preclude site building; they just extend the option to use low-impact, highly insulating bale walls to a range of builders and owners who otherwise would not consider the idea. And panelized systems can also be helpful to owner-builders who do not have access to a large labor pool: panels can be built on site by one or two people and tipped up in place, providing an option for those who can only build part time by breaking the process down into manageable sections that are protected from the weather as soon as they are stood up in place.

Small-scale production facilities

To me, one of the most exciting aspects of prefabricating straw bale walls is that the process

Any small shop space can make enough panels for multiple houses, using only basic tools and equipment.

favors the use of regional "micro-factories" rather than large, centralized production facilities. The investment required to start a panel-building facility is remarkably small — only requiring basic tools and equipment — and locally acquired straw bales, lumber and plaster materials are the most cost-effective options. Short transportation distances between production facility and building site also make economic and environmental sense. Prefabricated straw bale wall micro-factories are viable local business opportunities in communities anywhere in the world where there is a source of straw bales. Rural communities could benefit from the value-added production and supply of walls to nearby urban centers.

Practicality and idealism combined

As a designer and a builder, I'm a pragmatist as well as a strident environmentalist. Prefabricated straw bale wall panels — or S-SIPs (Strawbale Structural Insulated Panels), as they will be called in this book — are among a very small number of approaches to building that satisfy

both of these perspectives. In marrying all of the real and measurable ecological advantages inherent in straw bale building with the very practical need to make buildings that are affordable and simple to construct, this approach is one that is ready and waiting to help redirect the building industry in a much more environmentally responsible direction. Whether you are an owner-builder looking to build a single home or a developer looking for a way to green your next subdivision, I hope that this book inspires you in a meaningful way. There is ample evidence that straw bale walls work and work very well; now there is a way to bring those advantages to the modern construction marketplace.

Prefab panels are an exciting way to bring a promising building system to a mainstream practice.
Credit: Dan Earle

Chapter 2

Rationale

Why Straw Bales?

While it may not initially strike one as possessing ideal qualities for construction, there are many compelling reasons for using straw bales as a building material.

Great thermal performance

Though some enthusiasts seem to imbue straw with almost-magical insulating qualities, the truth is that typical straw bales do not have remarkable thermal properties. Most testing has shown R-values ranging from 1.5–2.3 per inch,[1] lower than many commercially produced insulation products. However, straw bale *walls* are widely attributed a whole-wall R-value of 30, which exceeds all current requirements in the International Residential Code (US) and the National Building Code (Canada). A more thorough examination of R-values is presented in the Material Specifications chapter.

However, these numbers don't tell the whole story because bale walls have real-world performance even better than their nominal R-value would indicate. There are several reasons for this, including a near-perfect distribution of thermal mass on the interior and exterior face of the wall, minimal thermal bridges in the wall, and a naturally airtight barrier on both sides of the wall. (See Building Science Notes chapter.) These factors combine to give excellent performance in a wide range of climates.

Good, cheap fill

Straw happens to be relatively inexpensive compared to manufactured insulation products and it comes in relatively large ready-made bundles.

Table 2.1

Material	Approximate cost* for 1 square foot @ ~R-30*	Thickness of insulation
Straw bales	$0.75 @ $3.00/bale $1.45 @ $6.25/bale	14–16 inches
Mineral wool batt	$1.40	7 inches
Fiberglass batt	$1.20	9.5 inches
Denim batt	$1.80	8 inches
Dense packed cellulose	$1.45	9 inches
Extruded polystyrene foam	$4.40	5.75 inches
Expanded polystyrene foam	$4.20	7.5 inches
	* cost are averages from building supply retailer websites, 2015	

The wide straw bale wall (anywhere from 14–26 inches wide for standard bale sizes) insulates very well for a low cost. A square foot (0.09 m^2) of bale wall at an approximate R-value of 30 would cost between $0.75–1.45. Bulk purchasing directly from farms can provide lower costs.

Decent structural qualities

Unlike the batt insulation materials in the cost chart shown here, straw bales have a density that allows them to play a structural role in the building. The straw bales in a wall are not the primary structural element of the wall; that role is handled by the vastly stiffer plaster skins[2] for some types of S-SIP. Structural sheathing and/or structural frames can give other types of panel the required structural rigidity.

Bales can be stacked without the need for any framing and still keep their form, and they can act as an excellent substrate for plaster, eliminating a number of components compared to

conventional insulation types. They can even hold up a roof temporarily, and (with the right design) absorb earthquake forces for a surprisingly long time — giving a bale wall a resilience that can't be found in other insulation materials.

A by-product produced in vast quantities

Grain farming produces tens of millions of tons of straw annually. Each year, enough straw is produced in North America to build hundreds of thousands of homes. In the U.S., 54–56 million acres of wheat are planted annually,[3] which could produce 6–7 billion construction-grade straw bales, or about 15 million homes each year. And this is only a single grain crop; there are many other viable crops for making straw bales.

Good carbon sequestration

Approximately 40–50% of the mass of a straw bale is carbon.[4] At the code minimum of 6.5 pounds per cubic foot (100kg/m^3), every 14″×18″×32″ (355×457×800 mm) straw bale contains about 12–15 pounds (5.44–6.8 kg) of carbon. So, a typical 4×8-foot straw panel at the minimum bale density contains about 82–102 pounds (37–46 kg) of carbon. This is carbon that has been taken out of the atmosphere in a single growing season, and it will be contained in the wall of the building for a significant period of time. Wooden elements used in the construction of the panel also sequester carbon at a similar ratio of mass to weight.

As the harvesting and manufacturing of straw bales has a carbon footprint that is tiny compared to other insulation materials, this volume of carbon tied up in a straw bale panel can add up to a significant reduction of atmospheric carbon. A single 2,000 square foot (186 m^2) home would typically use 40 straw bale panels, which means it would sequester approximately 3280–4080 pounds (1488–1850 kg) of carbon!

In Canada, about 200,000 new homes are built each year. If they were all built with straw bale panels, an astonishing 328,000–408,000 tons (298–370 million kg) of carbon could be sequestered annually. That would be a sizable contribution to meeting greenhouse gas reduction targets.

Nontoxic building material

Unlike most other building insulation materials, straw is very benign. Harvesting and baling do not involve any industrial processes or

Table 2.2

Material	Embodied carbon by weight*	Embodied carbon for 4x8 foot wall @ R-28**	Carbon footprint after sequestration
Straw bales	0.063 $kgCO_2e/kg$[5]	8 $kgCO_2e$	-42.8 kg per panel
Mineral wool batt	1.28 $kgCO_2e/kg$	21.75 $kgCO_2e$	21.75 kg per panel
Fiberglass batt	1.35 $kgCO_2e/kg$	17.6 $kgCO_2e$	17.6 kg per panel
Denim batt	1.5 $kgCO_2e/kg$	22.45 $kgCO_2e$	15.45 kg per panel
Dense packed cellulose	0.63 $kgCO_2e/kg$	41.3 $kgCO_2e$	10.3 kg per panel
Extruded polystyrene foam	3.42 $kgCO_2e/kg$	38.5 $kgCO_2e$	38.5 kg per panel
Expanded polystyrene foam	3.29 $kgCO_2e/kg$	37.25 $kgCO_2e$	37.25 kg per panel
	* figures from Inventory of Carbon and Energy (ICE) 2.0	**material densities from *Making Better Buildings*	

chemicals, and nothing is added to the straw in the bale. The straw does not off gas any toxins and remains a stable, inert natural material in the walls of the building. However, bales can contain dust and particulate, especially if stored in a barn, and appropriate breathing protection should be used during installation.

Why in Panelized Form?

Most of the benefits outlined above are as true of site-built straw bale walls as they are of prefabricated straw bale panels. So why panelize this wall system?

Labor reduction

Relatively high labor input has always been an issue with site-built straw bale walls. The stacking of the bales is not particular labor intensive, but the plastering requires many hours, a lot of scaffolding, and much skill to apply three coats of plaster to all wall surfaces. Wet-process *panels,* on the other hand, can be plastered with the wall in a horizontal position, using the panel framing to create a "container" for the plaster and a screeding surface to level the plaster. Plus, the plaster can be applied in a single coat because there are no issues with slumping and cracking as would happen with a single thick coat applied on a vertical surface. Plastering labor can be reduced by as much as 75% for panels as compared to site-built walls.

Site management

Straw bales are a bulky material, and coordinating their delivery to job sites — especially urban sites — is difficult. On-site storage of bales is highly inconvenient and messy, as large amounts of loose straw accumulate and spread around the job site. On-site plastering is also a very messy process, with large amounts of dropped plaster requiring thorough masking of all surfaces in and around the building and a lot of cleanup labor. By arriving on site with the wall system already finished, these hurdles are overcome, which could even promote the adoption of straw bale walls in more densely populated areas.

Predictability

Poor weather conditions don't slow down or halt a project, because the walls can be built indoors. Rain and cold temperatures don't affect the quality of the walls, and no on-site time is spent tarping or heating a project to try to keep a project moving.

Shortened build cycle

Panelized walls are installed very quickly — much faster than the on-site construction of any wall system. This greatly reduces the length of the on-site build cycle, helping projects to be completed faster and lowering costs for the builder.

No retraining or reskilling of on-site builders

A panelized straw bale wall does not require any special knowledge of straw bale construction or plastering for installation, allowing crews trained in general residential or commercial construction to take responsibility for the installation process, and presenting them with walls that accept doors, windows and roof framing in conventional ways.

Who Would Want to Build with Panels?

There are many potential markets for prefabricated straw bale wall panels. Regardless of the market being addressed, one of the most attractive elements of this approach is the low cost of getting started. The initial investment in tools

and machinery is very low, and only a flat and (preferably) covered space is needed. Getting started in the business of building S-SIPs has an impressively low entry threshold.

Stand-alone manufacturers

Several companies around the world have formed as straw bale wall panel manufacturers, specializing only in the building and installation of this type of wall system. With energy efficiency, carbon footprint, environmental impact and the high cost of labor being key issues in the construction industry, opportunities exist for companies with a product that can address all of these issues in a cost-effective manner.

Construction companies

Builders in the residential and commercial markets can benefit from building their own prefabricated wall panels. Crew members can build walls during slow seasons or during downtime, keeping workers productive. A stock of ready-to-install walls can allow more jobs to be completed, especially in climates with a limited building season or unpredictable precipitation patterns.

Owner-builders

A panelized system can allow an owner-builder to create a straw bale wall system without the need for a large crew. Wall panels can be built one at a time on the building foundation and tipped up into place at any pace or on any schedule.

Farmers

Wall panels can be built on the farm where the straw is grown, giving farmers a value-added option for their straw bales. Panels can be built during slow seasons or bad weather to maintain productivity and income diversity.

First Nations

Many First Nations are experiencing housing shortages. Panelized straw bale walls can be built in the community they are intended to serve, reducing construction costs and providing employment. Wall manufacturing could continue to be a source of revenue once immediate demand has been satisfied.

Opportunities for Innovation

It is early days for prefabricated straw bale wall panels. Most markets are wide-open to be served, and the technology and processes for building the panels are in their infancy. Current panel builders are using a lot of tools and materials borrowed from other types of construction, and none are employing a high degree of automation. All are working with field-produced bales, but the development of an on-site bale press that converts low-cost bulk straw (from jumbo round or square bales) into precisely sized, consistent bales would provide the significant advantages of consistency and further labor reduction. This is an exciting field for those with a passion for creativity and refinement of processes.

Notes:

1. *Design of Straw Bale Buildings.* Bruce King, Green Building Press, 2006.
2. Ibid.
3. United States Dept. of Agriculture, Economic Research Service, Wheat Data Yearbook 2016.
4. "Carbon sequestration in European soils through straw incorporation: Limitations and alternatives." D.S. Powlson et al.
5. "Establishing a Methodology for Carbon Sequestration in Cotton Production in the US," Lanier Nalley et al.

Chapter 3

Material Properties and Appropriate Use

General Use Parameters

Prefabricated straw bale walls can be used as exterior and/or interior walls in most low-rise (three story or less) construction scenarios described in the International Residential Code (US) or in Part 9 of the National Building Code (Canada).

The *2015 International Residential Code* includes *Appendix S — Strawbale Construction,* which outlines prescriptions and performance for site-built straw bale walls that can be applied to prefabricated straw bale panels in most cases. The inclusion of this Appendix in the U.S.-based codes could be of great help to anyone producing prefab bale panels by simplifying the process of obtaining building permits.

Suitability for larger projects and/or projects covered by other codes must be determined by the appropriate design professionals. To date, the panels have been used successfully as curtain walls in larger projects, up to six stories in height.

The panels can generally be considered to have structural characteristics that are equivalent to those of conventional wood frame wall systems and can be used in scenarios where wood frame walls are considered by local codes to provide sufficient structural integrity. Structural analysis for particular applications must be considered (see Testing Data in Resources). Panels can be used as structural load-bearing walls or in conjunction with a structural frame as infill walls.

Load-bearing walls

Prefabricated straw bale walls can typically be used as load-bearing exterior and/or interior walls in any scenario in which conventional frame walls are used. In these scenarios, the walls carry all the dead and live loads and transfer these loads to the foundation.

Prefabrication makes large straw bale buildings feasible, like the Gateway Building at the University of Nottingham by MAKE Architects.

Infill walls

Prefabricated straw bale walls can be used as non-load bearing exterior and/or interior walls in any scenario in which a structural frame carries building loads and in which curtain walls are required. Infill walls can include those in which the frame of the prefabricated panel is designed to carry all structural loads without relying on the straw bale/plaster element.

Specific exclusions

Prefabricated straw bale wall panels should never be used as exterior walls in any below-grade applications, whether used as load bearing or infill. Use in flood plain areas should be restricted to elevations above anticipated 100-year flood levels.

Traditional timber frames can be wrapped with S-SIPs in a very straightforward marriage of techniques. Credit: Chris Magwood

Load bearing S-SIPs will receive all roof loads. Credit: Dan Earle