INTRODUCTION

In the past, it would have been unusual to talk about fabric covered structures and conventional buildings in the same sentence. The stark differences in materials, construction methods, and common uses of the buildings themselves made for a truly "apples and oranges" comparison.

©2015 Legacy Building Solutions, Inc.
Introduction

The tension fabric structure industry as a whole has made a series of incremental material advancements over the past few decades – along with some dramatic engineering strides in more recent years – evolving to the point where design considerations for fabric structures have become more and more similar to traditional building construction...if not practically identical in some cases. With a more level, “apples to apples” playing field, building users have been able to take advantage of fabric’s unique benefits without concern of sacrificing functionality or longevity.

However, as with any industry evolution, new technology is applied at different speeds and to varying degrees of success. In other words, some fabric building manufacturers are naturally much further ahead of the curve than others.

Based on best practices and lessons learned from industry research and direct experience with thousands of fabric building installations, this white paper draws on conclusions made by CEOs, project managers, engineers, installers and end-users. If the building selection criteria lead you to a fabric structure, the educational information presented in this white paper can provide you with critical knowledge toward making a sound purchase decision.

Frame and Truss Designs

Although the cladding material is the distinctive quality that sets all fabric structures apart from other buildings, the structural framing concepts across the fabric building industry represent significantly divergent construction philosophies. Some fabric applications demand a complex design while others simply require an inexpensive solution. As a result, different manufacturers employ various framing techniques, each of which presents their own advantages and disadvantages.

Single Tube Arches

Single tube arches consist of single tubes, usually in the shape of a half circle and 4- to 6-foot on center. Single tube arches are a good option for very small spans of between 10 and 30 feet. Buildings of this size may be purchased in self-install kits at hardware stores for very little cost. The frames are easy to build, often utilizing splices that slide together with very few fasteners needed. Additionally, the frames are lightweight and easy to disassemble and re-assemble, making them simple to relocate.
The downside of single tube building kits is that they are non-engineered, and they rely on temporary foundation options or those susceptible to deterioration such as wood posts, earth anchors or earth stakes. Furthermore, they are not customizable, instead only coming in predetermined sizes.

Aluminum Extruded Frames

Portability and appearance are the calling cards for fabric buildings utilizing aluminum extruded frames. These frames can be installed rapidly and provide a nice interior look, lending themselves best to rental applications such as tents or other temporary uses, though they often are erected as permanent structures. Aluminum frames can be delivered quickly for standard smaller spans and are also relocatable.
Life cycle cost is very expensive, another reason these frames lend themselves more to the rental market. Customizing aluminum extruded frames is difficult and expensive. Additionally, aluminum simply isn’t strong enough for buildings with large spans, and the strength concern also limits the flexibility of hanging and collateral loads from the frame.

Open Web Hollow Tube Trusses
For many years, open web hollow tube trusses – comprised of tubular steel chords with tubular steel or steel angles placed intermittently between the chords to act as a “web members” – were the industry standard for fabric structure framing. Offered at a relatively low cost, open web truss design still works as a basic option for standard size smaller spans. However, the evolving viewpoint on open web truss design is that the engineering is very subjective at best, with different engineers offering varying opinions about the structural integrity of one building to the next.

What can be agreed upon is that open web trusses are difficult to customize, so customers are usually stuck with whatever building sizes a manufacturer keeps in stock. Incorporating any requirements outside the norm, such as suspending hanging or collateral loads on the frame, is a cumbersome, time-consuming challenge, typically involving manual analysis that can take weeks.

Engineering aside, the fact that the tubes are hollow is a serious durability issue, particularly in applications where buildings are exposed to corrosive conditions. Corrosion can originate inside the tube – out of sight and undetected – and corrode the frames from the inside out. Once corrosion begins it can worsen quickly, and often the damage is irreparable.
Rigid Steel Frames

The turning point in fabric building design came in 2010 when Legacy Building Solutions introduced the application of fabric to a rigid steel frame. The use of solid, structural steel I-beams effectively eliminated the issue of corrosion originating inside a tube, while also bringing the proven engineering of rigid frame construction to fabric structures for the first time.

The strength of the structural steel frame provides several advantages, most notably the ability to use finite element analysis software to customize buildings to the exact width, length and height required...down to the inch. Structure designs can easily include varying column or foundation heights, offset peaks, lean-tos, overhangs and canopies. This design method utilizes sidewalls that are straight instead of curved, which maximizes the usable floor space and allows for much larger door openings, including extra-wide sidewall doors that are possible through the use of jack beams.

Engineered fabric structures with rigid steel frames have grown quickly in popularity because of the flexibility available to a wide array of building applications. It has proven particularly advantageous for structures requiring large spans. Furthermore, software can easily modify solid frame structures in just a
few minutes to handle additional hanging loads for conveyors, collateral loads, sprinklers or other systems.

![Figure V: Rigid steel frame construction](image)

This technology can be expensive for structures that only need small spans, and lead times can be longer than with comparable aluminum structures. Evidence has proven rigid frame engineering has given tension fabric structures the advancements to meet the demands of 21st century building users.

### Frame Coating Options

While fabric is often selected as a building material because of its corrosion resistance, translucency or other benefits, protection for the metal components and framing of the building must be considered as well. A number of coating options are available to meet the appropriate needs of a given building’s environment.

#### Hot Dip Galvanizing

Considered the best coating available for protection against corrosion, hot dip galvanizing is a procedure that binds a protective coating of zinc to steel – approximately 3.9 mils thick per ASTM A123 standards – through a metallurgical reaction.

#### In-line or Pre-galvanized Tubes

Typically referred to as Gatorshield®, in-line galvanizing offers just 0.9 mils of thickness and no protection inside the tubes or at welded joints.

#### Primer Paint

A good, low-cost option when corrosion is not a concern is to treat steel with a gray or red primer.
Powder Coat Paint

Though it is typically more costly, powder coat paint provides a great finish if a special color is desired.

Potential Concerns with Secondary Framing

Proper secondary framing can add strength and stability to a fabric structure. There are designs on the market, however, that are unnecessarily complicated and can weaken the building as a result.

Complicated Connections

Because of the superior strength associated with the rigid frame design, Legacy is able to avoid using purlin or strut connections that require complicated connecting brackets, where almost every other company relies on these secondary framing attachments. When other manufacturers install fabric, they disconnect the secondary framing members in order to pull the fabric and make the necessary bracket connections.

As part of its patented fabric attachment system, Legacy bolts secondary members directly to the steel frame, and they never have to be removed for fabric installation. This simple and direct connection ensures added stability for the life of the structure.

Roof Panels Attached To Secondary Framing

It’s important to understand that secondary framing members are almost always in compression, so attaching the roof fabric to framing members (purlins) is simply a bad design. During a wind event, purlins will experience greater compression forces due to the wind loads. If a fabric panel is attached, it will apply additional loads that pull the purlin out of plane, which drastically reduces the capacity and strength of that framing member.

Fabric Choices

The architectural fabrics available for today’s structures are far superior to those used in the industry 20 years ago. And more innovation continues to take place every day, with enhancements contributing to greater longevity and less maintenance while still providing ample translucency to allow users to take advantage of natural sunlight.
### Polyvinyl Chloride (PVC) Fabric
Though it varies by manufacturer, typically PVC fabrics are heavier and offer superior tear strengths. Because of its extreme durability, it’s not uncommon for a PVC fabric to last 25 years or longer. The primary disadvantage of PVC is its higher lifecycle cost. It also offers less translucency, depending on thickness and manufacturer.

### Polyethylene (PE) Fabric
PE fabric is lighter and more cost-effective than PVC, but still offers excellent longevity of more than 20 years in common applications. Translucency can be as high as 9-percent, and the material tends to clean itself very well during rainstorms. PE fabric falls short of PVC in tear strength, however, which can provide a formidable challenge in environments with extreme snow or wind loads.

### Ethylene Tetrafluoroethylene (ETFE) Film
A new product just hitting the market is ETFE film, which offers up to 80-percent translucency providing an excellent alternative for skylights and areas requiring a high level of light penetration. ETFE is very strong and durable, though also far more expensive than PE or PVC fabrics.
Attaching Fabric

It may be difficult to tell at first glance, but there are some critical and striking differences in how fabric is attached to different styles of structures. These differences can drastically impact the long-term success of a building project.

Mono-Covers

As the name implies, a mono-cover is one large piece of fabric stretched over an entire building. These covers are inexpensive to purchase and perform well under low wind loads, unfortunately these roofs are simply not built to last.

Figure VII: On the leeward side of a mono-cover building (left), it is common to experience at least 20 psf of suction with 90 mph wind load (this could be significantly higher). The Legacy roof system (right) experiences the same suction forces as mono-covers, which is 20 psf at 90 mph on the leeward side of the building without lifting.

An example of a poor design, the fabric on a mono-cover is attached only to the end frames, which is a serious engineering problem. When wind blows over the peak of a building on the leeward side, it comes into suction and lifts the fabric off of the structure, to the point where fabric is literally no longer touching any of the interior trusses. Fabric is not designed to handle those forces without support, and in these situations roof fabric can tear away from the building. Calculations have shown that mono-cover design typically experiences triple the amount of stress that it should, per fabric supplier recommendations.
Typical Keder Track Attachment

The typical keder track attachment method used in fabric structure installation is another example of a link to the industry’s imperfect past. The flaw in this process for many manufacturers is the need to disconnect secondary bracing and pull trusses out of plane in order to install the fabric. This is highly unsafe, as when the truss is pulled out of plane, it weakens its designed capacity. Furthermore, if a wind event occurs while the secondary bracing is removed, the building can be vulnerable to complete failure.

Another potential issue is the longevity of self-drilling screws that are commonly used with this style of attachment. Water can settle into the hole that’s created in the aluminum around a screw, which can lead to corrosion as aluminum, zinc and water are interacting.

The complexity of this method also means more time spent on or near the roof for the installers, increasing the chances of a jobsite accident. Installation errors are another inevitable side effect of this difficult process. And to make matters worse, the same challenges will arise again down the road if and when fabric panels need to be replaced.

Legacy Building Solutions Attachment System

The innovative, patented attachment system developed by Legacy Building Solutions essentially solves all the problems posed by other attachment methods. It starts with ensuring strength. Rather than depending on screws to secure the entire roof system, Legacy uses half-inch diameter bolts to clamp a keder rail to the top flange. This also contributes to corrosion resistance, longevity and lower life cycle costs as this method eliminates any areas where water could once accumulate.
Kedered panels are the best practice for attachment since they allow individual attachment to every frame. The system allows fabric panels to be installed without removing any secondary framing as the keder rail can move side to side horizontally on the top flange. This method is inherently safe during construction because no secondary bracing needs to be removed, nor is the frame ever pulled out of plane. Enhanced safety during construction is one of the driving forces behind Legacy's innovative design.

Figure IX: Legacy's patented fabric attachment and tensioning system
Engineering Considerations Impacting Design

Correctly engineered fabric structures, just like any conventional building, should take into account every detail of the structure's purpose, daily use, site environmental factors and building code requirements to ensure the building will be safe and durable for the long haul.

Environmental Conditions

<table>
<thead>
<tr>
<th>Factor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snow Load</td>
<td>The smooth surfaces of sloped fabric roofs inherently help relieve snow loads, but structures must still be designed to provide appropriate strength. The fabric, roof slope and frame structure should meet local snow load requirements.</td>
</tr>
<tr>
<td>Wind Load</td>
<td>Fabric structures should be engineered to meet wind load design guidelines specifically for the area where the building will be sited, ensuring sufficient stability during even the most prolonged and forceful wind events.</td>
</tr>
<tr>
<td>Seismic Load</td>
<td>A critical factor in earthquake prone areas is seismic load. Fabric structure frames should be designed to include any necessary reinforcement and flexibility requirements to meet local seismic construction regulations.</td>
</tr>
</tbody>
</table>

Site Conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Exposure</td>
<td>The terrain surrounding a specific site can influence the wind pressure on the building. Open areas that leave a fabric structure more exposed to wind typically require a higher overall wind pressure than areas where shelter is provided by trees, topography or even other buildings.</td>
</tr>
<tr>
<td>Roof Exposure</td>
<td>Reduced wind exposure can mean a higher roof exposure, since surrounding shelter may prevent the wind from blowing snow off the roof. It’s important to consider the wind and roof exposure together when determining final loads.</td>
</tr>
<tr>
<td>Occupancy and Importance Factors</td>
<td>Building codes include a hazard rating or “importance category” that relates directly to the expected use and human occupancy of a building. Higher occupancy buildings are considered higher hazard structures, as are buildings used as emergency shelters. Legacy designs its building to meet or exceed all occupancy categories.</td>
</tr>
<tr>
<td>Collateral Loading</td>
<td>A collateral load is an additional dead load applied to the structural frames that typically won’t change over time. Such loads commonly found in fabric buildings include indoor lighting, sprinklers and fire suppression equipment and HVAC systems.</td>
</tr>
<tr>
<td>Live Loading</td>
<td>Live loads account for movement of objects, material, vehicles and people. The live loads hanging from a fabric structure commonly include conveyor systems, overhead cranes, mezzanines and shelving.</td>
</tr>
</tbody>
</table>
Depending on the number of external walls that include openings such as overhead doors or air vents, a fabric structure can fall into different enclosure categories. The design must be able to withstand wind pressure changes and meet the codes associated with the building’s specified enclosure category.

<table>
<thead>
<tr>
<th>Enclosure Category</th>
<th>Thermal Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depending on the number of external walls that include openings such as overhead doors or air vents, a fabric structure can fall into different enclosure categories. The design must be able to withstand wind pressure changes and meet the codes associated with the building’s specified enclosure category.</td>
<td>Thermal factor correlates to the year-round interior temperature. The thermal factor will impact the calculation of the roof snow load.</td>
</tr>
</tbody>
</table>

Deflection Limits

Building codes include standard horizontal and vertical deflection limits, which describe the amount of movement the fabric cladding can handle under extreme conditions. For example, a fabric building may be designed with a vertical deflection of 3 inches, meanings that the roof will sag no more than 3 inches while experiencing maximum wind and snow loads. It’s common for building engineers to demand tighter deflection limits, which can be easily achieved in the design process by employing a heavier steel frame.

Building Options and Accessories

Fabric buildings are used in a wide array of applications, constructed in different climates, and designed to accommodate varying budgets and needs. A number of accessories are available to enhance fabric structures to meet particular project requirements:

**Liners**

Adding an interior fabric liner can enhance a building’s aesthetics, hiding the frame and insulation from view. They also serve a practical purpose, especially when storing corrosive materials such as salt or fertilizer, by keeping corrosive matter and dust from coming in contact with the steel frame. For storing corrosive materials, liners are very effective because they seal the building from the inside out.

**Insulation**

Buildings can be fully or partially insulated to enhance energy efficiency. Fiberglass batts ranging from R-19 to R-30 are common, but needs and options may vary based on climate and building use.
<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lean-tos</td>
<td>Adding a lean-to is a cost-effective way to add space for additional storage, office space or other uses, without drastically expanding the building footprint. Lean-tos are easily incorporated into rigid frame building design.</td>
</tr>
<tr>
<td>Overhangs</td>
<td>Eave extensions, canopies or overhangs can add attractiveness to a fabric building, while also helping to shed water and snow away from the structure.</td>
</tr>
<tr>
<td>Gutters and Downspouts</td>
<td>The curved or hoop shape of older style fabric buildings leaves no option but for rainwater to run down the sides. With conventional rigid frame design, gutters and downspouts can be added easily.</td>
</tr>
<tr>
<td>Icebreakers</td>
<td>Large chunks of ice and snow can slide off a roof and cause injuries or damage. Adding icebreakers to a building’s eaves breaks the chunks into much smaller pieces.</td>
</tr>
<tr>
<td>Awnings and Canopies</td>
<td>Awnings and canopies are additions that provide coverage over a building opening while adding architectural style.</td>
</tr>
<tr>
<td>Doors</td>
<td>The straight sidewalls associated with Legacy’s rigid frame design allows any type of door to be added anywhere on the fabric structure. Common doors utilized on fabric buildings include overhead doors, bi-fold doors, Megadoors®, bottom rolling doors, sliding doors and hydraulic doors.</td>
</tr>
<tr>
<td>Jack Beams</td>
<td>A good solution for wider sidewall door openings is a jack beam, a large horizontal beam that can support structural roof frames that land over the door opening.</td>
</tr>
<tr>
<td>Lights and Mechanical Systems</td>
<td>Fabric buildings are often designed to accommodate lights or mechanical systems needed to maintain a safe, comfortable operating environment.</td>
</tr>
</tbody>
</table>
Hanging Loads

Equipment loads affixed to the structure frames in Legacy buildings are calculated into the roof-load specifications. Building framing can easily be engineered to support conveyor systems, overhead cranes and the materials they carry.

Grain and Commodity Liners

In commodity storage applications, buildings can be engineered to account for the pressure of material pushing out against the sidewalls.

Foundation Choices

Several foundation options are available to give users flexibility based on the site and the potential need to relocate a building at a later date. It’s important to note, however, that some companies claim that their buildings can use a reduced foundation or no foundation at all. Make no mistake – a properly engineered fabric building that is intended to remain in one location for more than a few days will require a foundation.

Quick Install Foundations

A number of foundation options can work with minimal or no excavation needed, which works nicely when subsurface items cannot be disturbed. Foundations do still need to be engineered to handle the base reaction forces applied by the fabric building. Helical anchors are an especially good foundation for structures that will be relocated. Micropiles and earth-anchors can also be used. Ballast blocks may be used for sites that don’t allow any surface penetration whatsoever.

Precast Concrete

For many smaller fabric buildings, precast blocks and panels can make an excellent foundation. Precast foundations keep the structure in place, and provide a retaining wall when storing commodities. Because of their portability, the precast panels are also helpful if the structure will be relocated.
Cast-In-Place Concrete

Due to its strength, versatility and availability, cast-in-place concrete is the most common foundation material for tension fabric buildings. Typical foundations include poured reinforced piers, poured walls, and thickened edge slabs.

Fabric Building Quality Certifications

As with any industry, certain manufacturers are better at what they do than others. While it can be a subjective process to try to determine what companies are delivering the highest levels of technology and innovation, there are objective quality and performance standards that manufacturers can achieve to help customers make an informed decision.

ISO 9001:2008

Legacy has achieved ISO 9001:2008 certification, the highest quality management certification standard available in industrial manufacturing. Organizations that attain ISO 9001:2008 certification undergo an annual quality audit to ensure that every level of the organization – from engineering to manufacturing to customer service – is striving for constant improvement to achieve constant customer satisfaction.

CSA-A660-10

The Canada Standards Association (CSA) A660 certification program for steel building systems requires that steel structure manufacturers comply with applicable engineering criteria and building codes. To ensure design and production standards are met, manufacturing must obtain documented approval from a licensed professional engineer. CSA-A660-10 is the most comprehensive certification standard specific to the tension fabric building industry.
Fabric Building Companies Are NOT All The Same

As noted in the examination of fabric building factors throughout this white paper, there are a multitude of differences among the numerous fabric building manufacturers who serve the industry. Though most are well intentioned, many simply haven’t yet brought the level of their product offerings forward to meet the demands of the 21st century.

Experienced experts who recognized the shortcomings of traditional fabric structure design founded Legacy Building Solutions. They sought to greatly improve every aspect of the fabric building experience for engineers, project managers, site owners, purchasing agents, end users and building occupants. Though Legacy prides itself in striving to be the best in everything we do, there are a few key areas that deserve special recognition.

Superior Technology

Legacy was the first fabric building manufacturer to use superior quality, rigid frame engineering to deliver enhanced customization and flexibility to fabric structure design. We also developed a smarter, safer fabric attachment system that ensures optimal building longevity and life cycle costs.

Experience

Legacy’s experienced team has worked around the globe, building a cumulative total of 4,000 buildings covering over 35 million square feet in the last 20 years.

Professional Installation

Installing fabric structures requires extensive training and is best handled by experienced professionals. Legacy employs in-house construction crews that travel worldwide to erect fabric structures quickly and correctly.
Figure XII: Safety is a priority in fabric structure construction

Full Service

From the initial design concept to complete construction services, Legacy assists with fabric building projects. Whether acting as the general contractor, engineer, manufacturer, installer or all of the above, we provide the highest level of customer service in the industry – before, during and after the sale.