Sustainable Agricultural Building Design Using Locally Grown Danish Timber

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Abstract: The paper describes an ongoing project, a sustainable design of an agricultural building, part of an ecological meat production farm on the island of Glænø in Denmark. It is a low-cost design using local skills and materials. The building is resource saving on every level; it also utilizes excess heat and sun energy. The paper presents the overall sustainable design approaches and mainly concentrates on the design of the optimized timber roof truss which uses locally grown timber. The main design criteria for the timber roof structure are structural efficiency, buildability and aesthetic appearance of both the concept and detailing.

Keywords: Sustainable Design, Local Timber, Reciprocal Frames, Optimized Design.

The Design Context

In Denmark there is a great tradition in agriculture, especially production of meat, which is mostly produced in intense farming conditions. In recent years there are increased tendencies of ecological meat production, where the animals are let to graze freely in free-range farms. Undoubtedly the quality of meat produced this way is better, but often the cost of such ecological meat production is higher due to increased health risks for the animals, need for more space on the farms, the volume of meat production which is rather small in comparison to the intensive production etc. Although the government supports such initiatives, it is often that the most persistent farmers who through daily struggle manage to keep up the ecological farming. Despite the government's efforts to help ecological farming, its volume in comparison to intensive farming is still lower.

In the context of the above the task was to design a building, a new cowshed that would replace an existing one and provide home for the ecological meat production. The client strongly believes in sustainable approaches. Thus the building had to be designed to minimize resources both for construction, also to reduce operational energy use. The materials used in construction had to be local, also the building should use as much as possible local skills and easy to construct methods without any machinery beyond what is available on a typical farm. Lastly the building structure should be something other farmers could copy, almost build it themselves because it is easy to construct, it is efficient and beautiful. The building structure should challenge the existing approaches of designing and building farm buildings and offer new, improved and more sustainable ways.

The Brief

The brief was to design a building that would measure 16 x 32 meters in plan (figure1, bottom) without any internal vertical supports. As the aim was to create a new approach for farm buildings an important requirement was that the building from outside must have a conventional 30 deg. roof, (figure 1, top) just like any other typical farm building in Denmark would have.

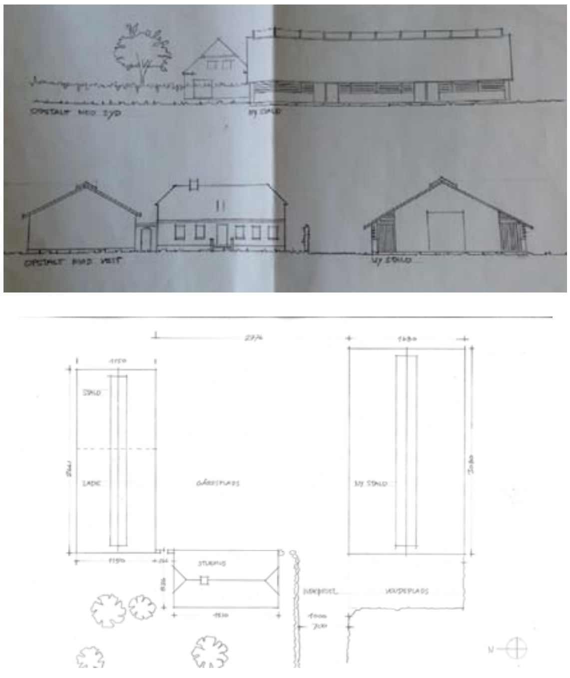

Figure 1. The Arangement of the Buildings Showing the Position of the New Cowshed (The Largest Building)

The client thought that if we challenged the external expression by offering a completely new form, the building would not fit in a conventional Danish farm setting. Furthermore, it would be unlikely that other farmers would use the idea for the roof structure. This gave a clear constraint to the possible geometry of the roof.

The Design

The building will be designed using concrete foundations and a concrete floor. The building design will be used as an experiment by trying to utilize the heat that is produced in the fermentation of the feces from the animals mixed with straw. The heat will be stored and transported through the concrete floor and utilized for heating. There will be a special system of pipes in the floor that resembles an above ground heat pump situated in the floor. The system is new and the client is developing it together with researchers from the Danish Technological Institute.

The roof has a good orientation and it will be used for solar energy with panels that will be fully integrated in the structure and not as an add-on often seen on farm buildings.

These, as well as the sustainable roof design, will make the building a showcase for sustainable design of an agricultural building in the Danish context.

The Timber Roof

A common approach when building an agricultural building in Denmark would be to use a prefabricated timber truss roof structure. This would be a relatively cheap and fast way to build a roof over a column-free space. A prefabricated timber truss was not an option for this project because it would have not followed a sustainable design approach, something that the client could not accept. The truss uses:

- C24 timber most likely imported
- Fully dried timber, thus has used additional heat for drying the timber
- Engineered connections that require a specialized construction team for assembly (often provided by the truss supplying company)
- Purely engineering aspects for structural performance thus has no consideration of aesthetic appearance of the overall structure and the details of the connections.

The prefabricated timber truss as a recognized structurally efficient option during the design process was used as a benchmark for comparison. In the design development, during each step of the process, each new design option was compared to the truss in terms of efficiency and the design was optimized continuously and accordingly. The comparisons guided the optimization process. During the design development the optimization was carried out to achieve minimal use of timber (Heschler *et al.* 2011) by achieving an efficient structural design concept, but also a design that was aesthetically pleasing with simple, efficient and beautiful detailing and a building that could be constructed with out machinery almost in a DIY way. It was a challenge!

The Design Development

The first initial ideas came from structures using small timber members that combined form stable assemblies (Larsen 2014). More specifically a structure inspired by Leonardo da Vinci's temporary bridges (figure 2) forming an Reciprocal Frame (RF) arch structure was the starting proposed design.

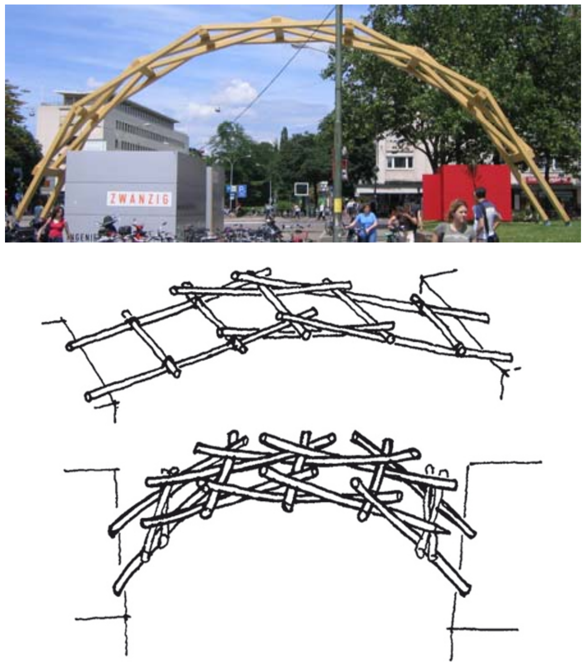

Figure 2. Leonardo da Vinci's Temporary Bridges

The idea to use a Reciprocal frame (RF) structure came because RFs are:

- Easy to construct due to the interlocking of the RF members (Baverel and Larsen 2011)
- Easy to handle because the members are small thus weigh less (Larsen 2013).
- The weaving effect of the interlocking structure offers a possibility of creating a distinct aesthetic

We all liked the appearance of the structure. After modeling the structural behavior we made a crude 1:10 physical model, which suggested ease of construction of the interlocking members and also, showed a very interesting aesthetic (figure 3).

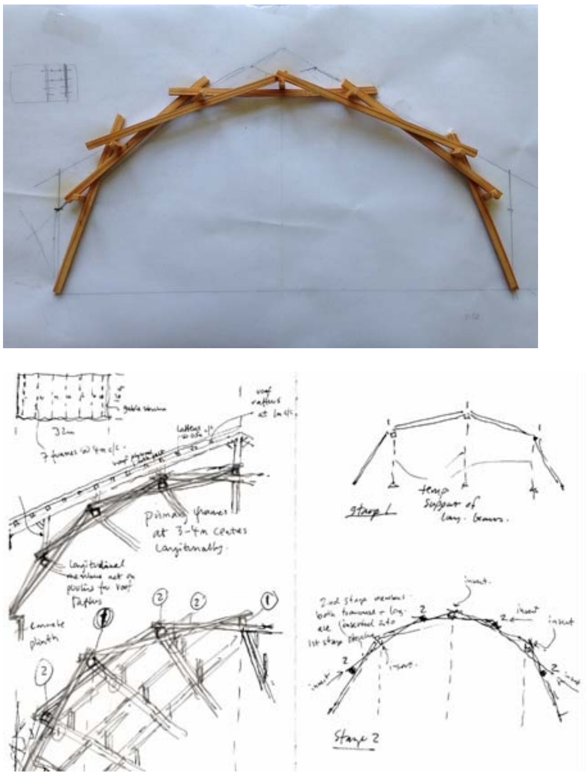

Figure 3. The First RF Arch Structure Proposal

Then we carried out a comparison to the prefabricated truss used as a benchmark. As we knew that we would be using locally grown timber (most of it fast grown spruce), as shown in figure 4, we could not count on more than C18, in some cases even less, yet the prefabricated truss was C24. We therefore modeled the RF arch both in C18 and in C24 and the volume of wood in C24 was compared to the volume of wood (also in C24) used in the prefabricated truss. It was clear when comparing the structural efficiency of the RF arch to the prefabricated truss, that the truss would be more efficient, so that did not come as a surprise. However, when looking more closely to the design, a further problem was that not only an arch was structurally less efficient, but had to be loaded with a secondary structure creating the 30 deg. sloping roof appearance to the roof. A simple solution of reducing the dead load would have been to clad the roof in a segmented arch form and not follow the 30 deg. sloping roof. The suggestion was not accepted by the client. He felt that a form like that would not fit into the context. We were back to the drawing board!

Several other concepts were considered and each time the concept was modeled and compared to the benchmark structure. It was clear that it would be difficult to fully match the structural efficiency of the benchmark structure because we were using local timber with lower grade, thus the design required larger sections. Furthermore an important consideration was the ease of construction and an

Figure 4. Locally Grown Timber (Spruce) Will Be Used for Construction

important compromise was to come up with a structurally optimized design that was aesthetically pleasing and easy to build. Although our design is using more timber, it is sustainable because:

- The timber is locally grown, comes from 400 meters away from the farm
- The timber will be dried outside and will not use any additional energy for drying
- The design avoids complicated construction methods.

At present the design development (figure 5) has achieved a design that is very close (about 10-15% more) to the use of timber of the benchmark structure. This was achieved through many iterations and design development. The final design (figure 6) is a Reciprocal Frame truss. Thus it is more efficient than an arch, avoids the dead load of a secondary structure by using the top cord of the structure for forming the required 30 deg. roof.

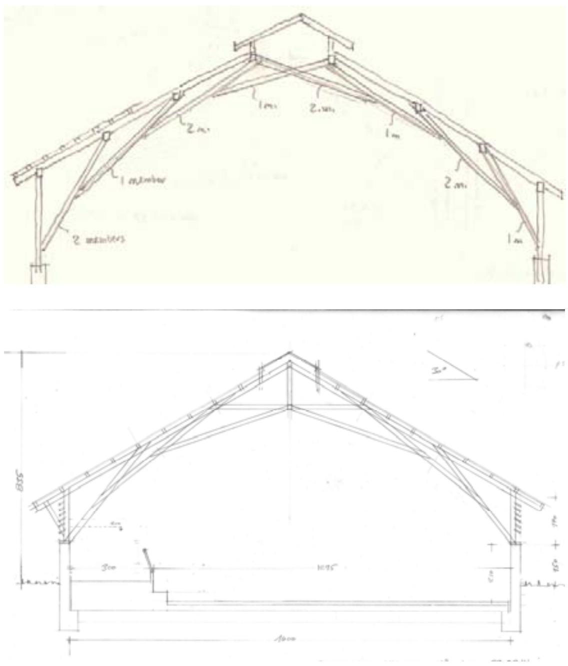

Figure 5. Steps in the Project Development – A RF Truss

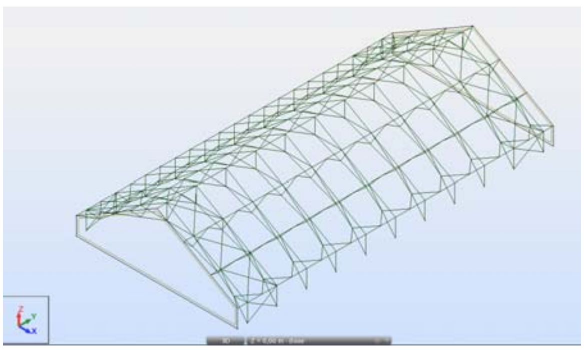

Figure 6. 3-D View of the Roof Structure

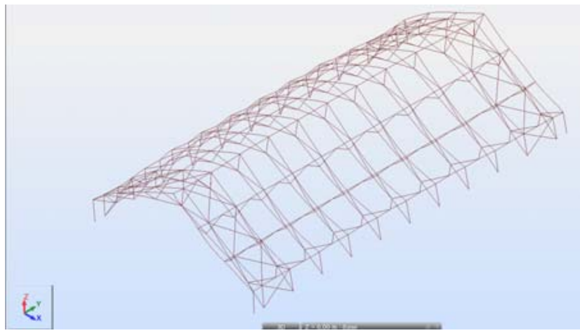

Figure 7. Perspective View of the Deformed Structure under the Wind Load

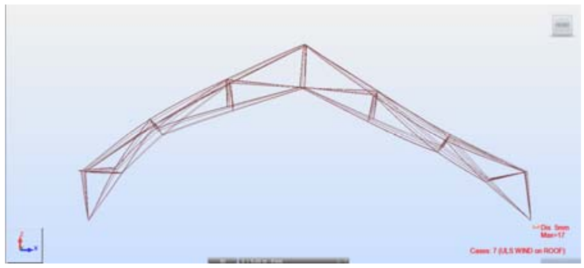

Figure 8. Elevation View of the Deformed Structure under the Wind Load

The following information is relevant to the design:

- The 3D computer model is constructed to analyze the overall stability of the structure under the combinations of loads, including s wind and snow loads (figures 7 and 8).
- All elements are assigned to pinned support condition (free to rotate at ends). Though the actual timber connections may transfer moments between the elements, they will become loose over years due to local compression deformations of the timber and eventually no moments would be possible to be transferred; thus they are calculated as pinned supports.
- In the computer model, the loads are applied on each frame as line loads, and the wind load on the gables are applied on pseudo-panels.
- The calculation is in accordance with the Eurocode with Danish National Annex.
- The structure is checked against the limit state design criteria, and the overall displacements of the structure are not critical as for the building does not include any brittle components.
- The material strength of the elements is specified to C18 with Service Class 2, although in some cases it may be lower.

To Be Done

At present the wood has been felled and imminently will be cut to the required sizes. It will then be left to dry for about a year. As the building will be an unheated space there is no need to fully dry the timber, but it will be sufficient to reach 18-20 %. To achieve that level it will be sufficient to dry the members in a covered, well-ventilated space (most likely a tent will be constructed over the timber). It will take some effort to cut the timber – about 16040 meters in total length. As the logs are in different diameters, drawings (figure 9) have been made for all the timber log sizes, suggesting how to cut the timber so that most is used and least is wasted.

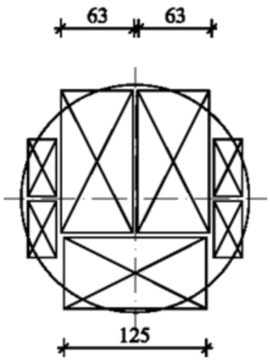

Figure 9. Example Drawing Suggesting How to Cut the Timber so the Least is Wasted and Most is Used

During the period while the timber is drying the design of the connections (Rizzuto and Larsen 2010) will be finalized. The final design details will follow the overall design strategy of achieving an efficient, easy to construct and crisp/beautiful expression simultaneously.

It is envisaged that work on site will start approximately one year from now. It is likely that the construction will give opportunities to involve students. Workshops in real scale and on a real project will give an opportunity to teach about the design process, optimization, the RF structural system and about how to work with wood. In that sense the project has a great educational potential.

Beyond the Project

There are several benefits and agendas that the project can influence:

1. Exploring the potential of RF trusses as a development from single layer RF structures to double layer structures. A study of the structural efficiency, geometry, aesthetic potential and applicability will give an overview of the real potential. Double layer RFs have not been researched in any depth yet.
2. Developing a new way of building agricultural buildings in the Danish context using local materials and local skills.
3. Using this and further projects for combined interdisciplinary educating of students (engineers, architects, carpenters, material scientists, timber education students, etc.)
4. Influence Denmark/EU to support small farms in the ecological meat production.
5. Influence more sustainable design and construction.

It will be a great success if only even a small part of these agendas are influenced by the project.

Conclusions

The paper presented an ongoing design project of an agricultural building to be constructed out of local timber. The roof structure uses an optimized RF truss system. The paper presented the design process of the roof structure and gave an overview of the future potentials of the process.

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