Building with cardboard: the reality

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1. INTRODUCTION

At the conference in Maastricht we reported on the development phase of the cardboard building being designed for Westborough school, in Westcliff-on-Sea, England. The building is now complete and being used by the school.

This paper reports on the reality of delivering a cardboard building. It presents a review of the environmental impact of the building, and whether the compromises needed to make cardboard work defeat the object of using cardboard in the first place.

The way in which the building was put together is also reported on. From this ideas on how to make cardboard building economic are developed. It is significant that although the raw materials are cheap, unless the processing can be made efficient, building with cardboard is actually an expensive way to build.

Finally we present ideas for future directions for cardboard that we are considering, or that could be taken up by others.

Figure 1: View into building from North side

Figure 2: Card tube used for air supply in toilet

2. WHY BUILD WITH CARDBOARD?

Cardboard has the potential to be a very valuable contributor to more sustainable construction in the future. It is made mainly from post-consumer waste paper and card, which is a material for which there is a limited market. The cardboard itself can in turn be recycled into more cardboard at the end of its life. The paper is of course originally sourced from timber (or other crops) and so is from a renewable source. Hence the raw material is an ideal candidate for any sustainable application.

Shigeru Ban is recognised for having led the way in cardboard building [Ban] and Buro Happold has been fortunate to have been able to work with him on a number of projects. These include the Japanese Pavilion at the Hannover Expo, and an arch in the garden of the Museum of Modern Art in New York. Perhaps more importantly he also devised an emergency shelter system using cardboard.

In terms of performance, cardboard like any material has a set of properties, and these are then affected by the form in which they are used. It will of course be obvious that these need to be considered when using the material, and the limits observed. Because we most often see cardboard in the form of packaging, we tend to think of cardboard as a very weak material, and one that burns easily. In fact it can be reasonably strong (we used a figure of 8 N/mm^2), and in a solid form is resistant to fire in the same way that timber is.

By using these properties we were able to use cardboard in a number of ways in the Westborough school project:

- Structural columns
- Partly structural panels for walls and roof
- Insulation (in the same panels)
- Air supply ducts

The largest user of cardboard is in the wall panels. These mean that around 30% of the volume of material used was cardboard. This rises to 50% if we ignore the floor slab, that was designed to allow any solution to be built on it - if we doing another project we would try to avoid using concrete for this. Of course by weight the percentage is much lower, because card (especially as honeycomb) is so light.

The walls and roof were calculated to have a 'U' value of around 0.3 W/m^2K, comfortably better than the Building Regulations for the UK (0.45). The card system is therefore able to play both a structural and thermal insulation role at the same time. It would be valuable for the thermal performance to be investigated in detail.

The extent of the potential strength of cardboard was demonstrated by an experiment carried out for the BBC TV programme 'Tomorrow's World'. We designed and built a bridge using the same
materials as the building, and it was more than strong enough to carry a car - see figure 3 below.

The final positive property to raise is the relative cheapness of the raw material. The 5 mm thick board costs of the order of 2.5 Euro per m^2, while the tubes cost around 3 Euro per linear metre for a 20 cm diameter tube. It is very important to note that the raw material may be cheap but the processing to make it work is not necessarily as cheap, and the end product may not be as competitive as expected.

Figure 3: Car on cardboard bridge

3. THE PROBLEMS OF BUILDING WITH CARDBOARD

The reader of the previous section may emerge wondering why cardboard isn't being used everywhere already! Of course there are reasons, some of them are associated with the weaker features of cardboard.

3.1 Creep

Creep, or visco-elastic deformation under load, affects all materials to some extent, but because of the shorter fibres in card, it is affected more than timber for example. As a result it is only possible to use a small proportion of the potential full strength of cardboard for long term loads. We used a factor of safety of 10 for the load bearing columns. The wall of tubes in the picture below would work with only 2 tubes for a short period. In the panels making up the walls this problem is avoided as they are edged with timber, and this helps to carry the permanent loads. The card does provide stiffening to what is effectively a timber frame, and carries wind loads.

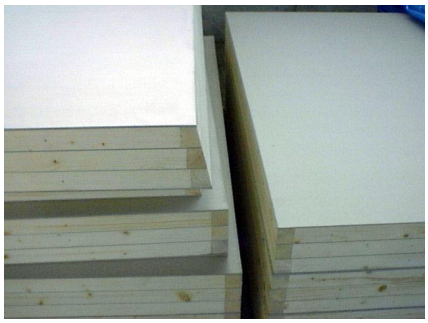

Figure 4: Panels showing timber edge

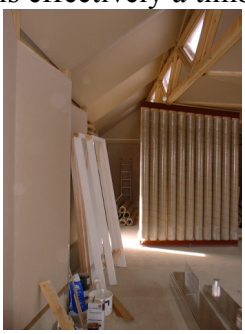

Figure 5: Tube wall in place

3.2 Water

The reason that card can be recycled is that the glue that holds the fibres together is soluble in water, meaning that card is vulnerable to water. In order to use it, card must either be protected from water, or treated to make it waterproof itself. This is one of the principle compromises that must be made in using cardboard.

There are a number of possible additives that can give cardboard different levels of protection from water. The most effective of these leave the material not as cardboard at all, but a composite board of some sort, usually with a non-recyclable resin of some sort binding the fibres. However

the completely untreated card tends to absorb water from the air, and so is vulnerable to normal conditions. Hence we chose to use a water resistant additive commonly used by the board maker to prevent this absorption, but to leave the cardboard recyclable.

To provide the protection from bulk water, there is no alternative to covering the surface with something else. At Westborough we used a very thin 'poly' layer in the inside, and a more robust building paper on the outside, followed by a fibre-cement board as over-cladding. This outer layer also provides impact resistance, and fire protection. This over-cladding is another aspect that could probably be improved upon in another project. We also built the main structure under a temporary roof.

3.3 Fire

Obviously paper burns, but solid card is more inclined to char than to burn rapidly. In a fire test carried out for the project a solid 5mm board narrowly failed the test for 'Class 1' spread of flame, which is a very onerous test. Given the size of the building we could have quite easily used a fire engineering argument to remove the need for any fire protection, as it is most unlikely that any loss of life would occur in a fire. However this does not account for the damage to property, and so we decided to treat the exposed card surfaces (the ceiling) to give better fire resistance. The images below are from another test for the Tomorrow's World programme, and show the flame being applied and the limited damage that this caused.

Figure 6: Fire test underway

Figure 7: result of fire test

3.4 Costs

As raised earlier, the raw material is very competitively priced. In our project however the cost of the processing to deliver the panels meant that it would have been cheaper to have used conventional bricks and mortar - and much easier for the builders. This is not however in the nature of the material but in the fact that the industry is not developed to deliver the product in a cost effective way. This leads into the next section.

4. THE FUTURE FOR CARDBOARD IN CONSTRUCTION

Figure 8: The finished building

What the successful delivery of the Westborough School after-school club building shows is that there is potential to use cardboard in a variety of ways in mainstream construction. What it does *not* show is that there is a real future for cardboard in construction.

Following the completion of the project we have had a very large amount of press and media interest in the project, with at least 100 articles written and 25,000 visitors to the project website, www.cardboardschool.co.uk, especially following a broadcast on CNN. However in spite of a large number of expressions of interest, at the time of writing we are not working on another project of a similar nature.

The way forward?

For cardboard to play a part in more sustainable construction it needs to find a market role where it can win a significant market share. Although one-off projects are excellent for raising awareness, it is the bulk of material that matters - we need thousands of tonnes of it to be used, displacing other more energy and raw material intensive materials. Further it has to work well in these applications so that the whole life impact is reduced.

It is unlikely that there will ever be many whole buildings built mainly in card. The structural performance is such that for most circumstances other materials will be better. The Westborough project was seeking to use card everywhere possible as a demonstration of what can be done, and is not expected to replicated directly.

Hence the next step needs to be a move toward more commercial, large scale development of one or a number of products based on cardboard. One or a number of organisations will then need to invest the resources needed to turn an idea into a real commercial product to compete in the market place. This must involve mass production of some form, if card is to compete with other materials.

There are many ideas floating around that could work, and we are hoping to be involved in developing a number in the future. The most obvious include:

- Panels for internal walls
- Ceiling or floor panels
- Temporary, cheap buildings
- Emergency shelters
- Garden buildings
- Parts of system-built structures

There are already some applications where cardboard is used, particularly in doors and some types of furniture, and the tubes are used for column forming and piling. What we see as likely to happen is the gradual appearance of a number of other products, to allow the use of cardboard to grow in construction.

5. CONCLUSIONS

In the Westborough School project it has been shown that cardboard can play a useful role in a bespoke, demonstration project. The question going forward is whether there is a place for the wider use of cardboard in construction?

The conclusion of this work is that there definitely could be, but that it will take a number of further commercial developments and financial investments to make it a reality. If this happens then cardboard can play a part in making construction more sustainable.

REFERENCE

Ban S 1997 ed. Galfetti, G G, *Shigeru Ban* (CG portfolio), 1997.