Figure 172 Avocado box: dotted lines indicate structural design elements that increase the overall strenght of the box

08 | MATERIAL SELECTION

The rationale for investigating cardboard as a feasible alternative was instigated by the structural integrity demonstrated in an avocado box and gradually developed to become the primary material in the development of the design proposal.

Cardboard is in the process of developing from a packaging material into a structural material with it's own language in terms of architecture. This chapter provides the grounds for establishing cardboard as a viable building material.

The construction of a seemingly innocuous avocado box is intriguing; a well engineered product designed to withstand the cold and damp of a refrigerated container, the lateral forces of a ship rolling at sea and the pressure of a ton of other boxes on top of it, all within strict material economy.

The box serves as an remarkable example of the strength and resilience that cardboard can achieve. The technology is there and available for use in the architectural field, it's just not entirely accessible. Eekhout,Verheijen & Visser[1] Maintains that:

> The paper and cardboard industry has a lot of knowledge about these products, but in an entirely different field of application and on a completely different scale than in the building industry, where materials are described with mechanical and physical characteristics and accepted rules (like tensile strength, bending strength and classification of quality).

Van Dooren & Van Iersel[2] describes this difference as a difference in thinking:

> An architect thinks in square metres and a paper manufacturer in grams; for the architect A4 is 210 x 297 mm, for the manufacturer 80 grams.

The unknown qualities of cardboard requires it's own architectural language.[3]

> In further research, the demanded mechanical and building physical characteristics, standards, design rules and guarantees will have to be determined. Each industry has it's own 'language', with specific definitions and values. Cardboard, as it's currently produced, is meant for packaging etc. The machines and mind set are aimed at just that.

The use of cardboard in the building industry would require the adoption of architectural standards and terminology for the development of a variety of 'building grade' cardboard.

The thesis aims to contribute to the feasibility of cardboard as a building material through employing an interdisciplinary approach. For this a certain degree of working knowledge is required to encapsulate the principles of the packaging industry into a plausible architectural solution.

8.1 WHY CARDBOARD?

Up till now research has revealed some of the most prevalent pressures involved in disaster response. Establishing a framework of shelter guidelines and context have provided sufficient parameters for concept generation and material selection. The following attributes were deemed important in PART ONE.

8.1.1 ADVANTAGES:

(a) Economy

It goes without saying that economy will always be a primary concern when it comes to developing sheltering solutions. This is not just to the advantage of the relief organization/ donor but could also have great potential in offering the end user with an adaptive longer term use.

1 Eekhout,Verheijen & Visser (2008:44-45)

2 Van Dooren & Van Iersel (2006:58)
3 Van Dooren & Van Iersel (2006:58)

Studies[4] have shown that when cardboard is used/applied [as insulation] in conjunction with other typical low cost construction materials, the improvement in thermal insulation can decrease annual energy expenditure by up to 75%.

Another benefit in designing with a low cost material is that it provides a reasonable margin for experimentation and testing of ideas and applications.

(b) Weight

The light weight of the material is very desirable for transport and handling during assembly.

(c) Availability

Cardboard is essentially a recycled product. It is readily available just about anywhere. The manufacture of cardboard is a huge industry in South Africa and has one of the highest recycling rates of any material, employing a virtual army of the very poorest in the collection for recycling.

(d) Manufacturing

Corrugated cardboard is manufactured in standard size 3-3.6m x 2.4m sheets that are available in a wide range of thicknesses [paper weight] and profiles.

Die cutting is a very flexible and low cost, high volume process. It uses steel rulers attached to either a 'roller' or a flat plate to cut and crease corrugated cardboard sheets into the designs. Tens of thousands of the same patterns can be cut from a single die.

(e) Post production: colour printability

It must be said that once the functionality of the product could be proved the flexibility of die patterns and graphic design presented the most exciting opportunities for the interior atmosphere.

The freedom of providing endless variations of interior spaces, at minimum cost, enables the project to improve the living environment disaster victims mostly have to contend with.

4 Mathews *et al* (1995:)

(f) Sustainability / life span

Sustainability is imperative. Sinclair[5] maintains that:

> [w]hen you are living on survival, sustainability is not a choice its a way of life; you have to know where your energy and your resources come from and to use them in the most efficient and innovative way.

Cardboard is a natural material from a renewable resource - in essence it is already recycled and can be recycled again and again once its served it's purpose.

Untreated cardboard is an environmentally positive material. There are various additives and coatings available that can be added during and after the manufacturing process to enhance the material properties.

Although "In a number of cases when the properties of cardboard improves the ability of the material to be recycled decreases".[6]

It is important to be aware of these implications - shall be discussed later in this chapter.

(g) Strength

In an interview with Verb Crises Shigeru Ban[7] points out that; "the strength of a structure is not dictated by the strength of the individual materials."

Cardboard displays similar properties to that of wood. It is an anisotropic material (strong dependant on direction of use) Hence Ban referring to cardboard as 'evolved wood'.[8]

For the purposes of the study the following rules of thumb[9] suggested bu Van Dooren & Van Iersel where used:

> Actual rules of thumb or calculated data, used in the building industry for the mechanical properties of materials, have not yet been acquired. For now we can only give a coarse direction. The compression and tensile strength differ depending on fibre direction; parallel to the machine the strength is greater than perpendicular to it (anisotropy; comparable to the character of wood).

5 TEDtalks (2006)
6 Eekhout, Vermeijen & Visser (2008:43)
7 Verb Crises (2007:120-121)
8 Van Dooren & Van Iersel (2006:16)
9 Van Dooren & Van Iersel (2006:66)

The strength of cardboard primarily depends on the raw material composition, method of production and material structure.

Material can either be from virgin fibers [VF] or recycled fibers [RF]. Virgin fibers demonstrate a slightly higher resistance to moisture than recycled fibers. The production method influences the fiber direction.

Some of the main cardboard products available in South Africa are:

Figure 173 Corrugated cardboard profile

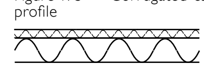


Figure 174 Roller die used to cut shapes out of flat sheet corrugated cardboard, Nampak Corrugated

Figure 175 Dufaylite is an expandable honeycomb structure used in hollow core doors, Disaki

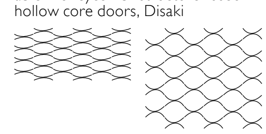


Figure 176 Xanita board is made from layers of corrugated cardboard

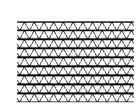


Figure 177 Stacked angle boards at the Disaki factory, Wadeville

Figure 178 Stacked cardboard tubes at the Disaki factory, Wadeville

8.1.2 CONSTRAINTS

At first glance moisture and flammability are the most prominent issues constraining cardboard from being used in buildings.

(a) Creep

Cardboard is susceptible to creep[10], limiting the span it can effectively achieve. This can be overcome through choosing a structural system [construction method] that strengthens the material and increase rigidity.

Eekhout, Verheijen, & Visser[11] have found that "[w]ith a folding construction relatively large spans can be made because of the form stiffness achieved by the shape of the structure".

Cardboard's susceptability to creep depends on the type of board and medium, where the pressure is applied and relative humidity the cardboard is exposed to.

(d) Poor moisture tolerance

Cardboard has a relatively low moisture tolerance which greatly influences it's structural properties. Van Dooren & Van Iersel[12] explains that "[u]ntil about 7% of water inside the cardboard it retains its basic strength. This equals the humidity of a 'normal' indoor climate. When the amount of moisture exceeds 7%, the strength diminishes rapidly."

Humidity can be mitigated through additives and coatings such as PE foil (multished) or waterproofed with a polyethylene film (PET). UV light breaks down the top protective layer within 3-6 months. The use of polyethylene is not ideal as South Africa has rather severe sun exposure - globally South Africa constitutes 60% of the total countries receiving more than 6kW/hours per day.

(c) Vulnerable to concentrated loads

Glued connections are the most stable. Because of cardboard's fiber structure point load connections should be avoided. The packaging industry use a variation of gluing, stitching [stapling] and tape to distribute the load the package has to withstand.

(d) Insects

Cardboard is a cellulose material and again, as in the case of wood, requires protection from insects and pests. This can also be solved by applying additives during the manufacturing process.

These constraints should be seen as a design challenge that can open up new possibilities and juxtaposition.

10 Eekhout, Vermeijen & Visser (2008:42)
11 Eekhout, Verheijen, & Visser (2008:35)
12 Van Dooren & Van Iersel (2006:70)

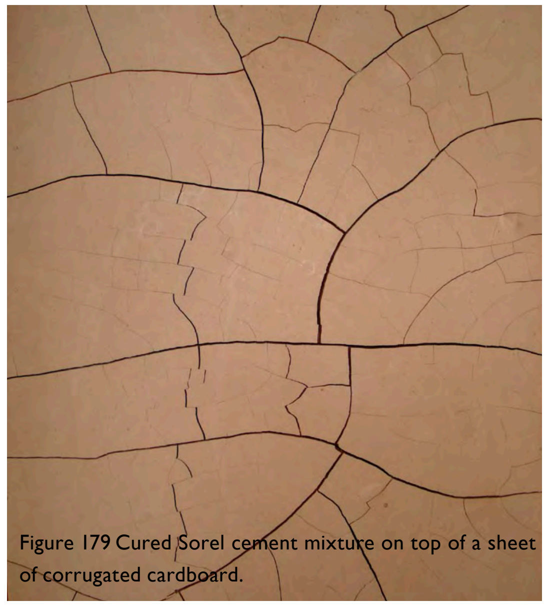


Figure 179 Cured Sorel cement mixture on top of a sheet of corrugated cardboard.

8.2 MATERIAL EXPERIMENTS

8.2.1 FIRE RESISTANCE

Sorel cement is a mixture of magnesium oxide and magnesium chloride. It is lighter than other cement products, has excellent fire resistance properties but poor water resistance.

Sorel cement is widely used in[13] industrial floorings, fire protection products, grinding wheels, abrasive stones and artificial stone ornaments.

DESCRIPTION:

A mixture of Sorel cement was applied to a corrugated sheet to evaluate how it bonds to cardboard and how it reacts to an open flame.

CONCLUSION:

Sorel cement becomes brittle upon setting which does not work well with the flexibility of the cardboard sheet. The mixture is too thick to penetrate the cardboard, and instead forms a layer on top of the sheet. The water content of the mixture drains quickly leaving the cardboard soggy and causing the cement to cure too fast.

Given this, the layer of Sorel cement provided an excellent fire resistant coating, even under extreme temperatures the cardboard did not singe or catch fire.

13 Nedmag Industries Mining and Manufacturing B.V (2009:[1of1])

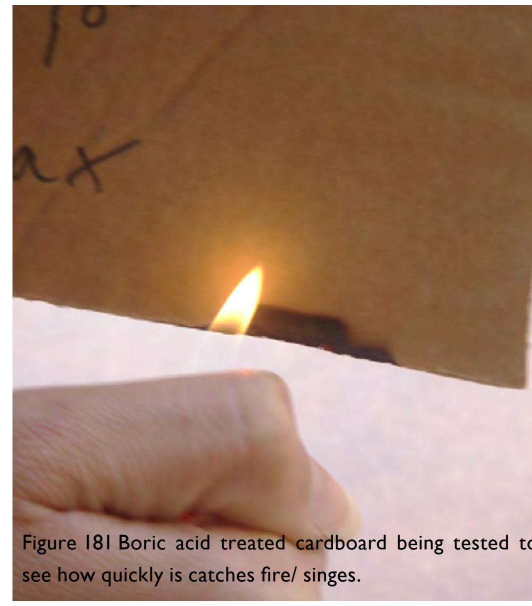


Figure 181 Boric acid treated cardboard being tested to see how quickly is catches fire/ singes.

8.2.2 FIRE RETARDANTS

Boric acid is a salt of the Borax compound [also known as sodium borate, sodium tetraborate/ disodium tetraborate]. It is a water soluble white powder consisting of soft colourless crystals.

Boric acid is used in a variety of applications[14] such as weatherproofing and fireproofing fabrics, ointments, eye drops, soaps, as a preservative, in the manufacture of cements, glass, leather and artificial gems, as an insecticide for cockroaches and carpet beetles, and in fungus control for citrus fruits.

The Smart Living Handbook[15] suggests soaking cardboard in a solution of boron as a low cost fire retardant before installing it as insulation.

DESCRIPTION:

Two experiments were conducted one using a 4% solution of Borax and the other a 8% solution. The cardboard samples were soaked in a boric acid solution and left to dry before being tested for rate of ignition.

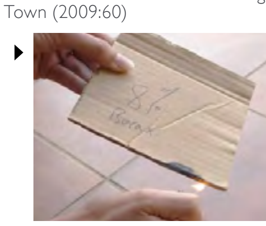
CONCLUSION:

Both the 4% and the 8% treated cardboard showed significant resistance to burning. Although the 4% singed quicker than the 8%.

14 Australian Government: Department of the Environment, Water, Heritage and the Arts (2009:[1of1])
15 Sustainable Energy Africa, Amathemba Environmental Management Consulting & City Of Cape Town (2009:60)

Figure 180 Brittleness of Sorel cement after curing on cardboard

Figure 182 Cardboard samples being tested (4% and 8% boric acid solution)



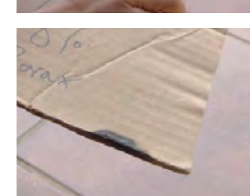


Figure 183 Cardboard frames with various coatings being tested for water permeability

8.2.3 WATER IMPERMEABILITY

DESCRIPTION:

This experiment was intended to be a quick exercise applying as many different coatings with materials commonly found around the house.

The goal was to investigate rate of structural decay when cardboard is exposed to outdoor conditions.

CONCLUSION:

Experiment clearly indicated that where the internal corrugation layer was sealed the integrity of the material remained intact for longer. It is therefor imperative that where possible cardboard should be kept away from the ground unless sealed and used in conjunction with other anchoring materials.

The stone sealant performed remarkably well as did the cardboard shell covered with the self-adhesive film.

NONE [control]

[raw material]

◀ DAY OF INSTALATION AFTER 7 DAYS ▶

AEROSOL PAINT

Plascon Aerolak [gloss black]

TYPICAL APPLICATION: indoor and outdoor use for any spray painting or touch ups

INTERIOR PAINT

Plascon double velvet [dove grey]

TYPICAL APPLICATION: indoor wall finishing

SELF-ADHESIVE FILM

AVERY GRAPHICS [gloss white] PVC FILM: 70 microns ADHESIVE : acrylic solvent based adhesive.

TYPICAL APPLICATION: 3 indoor signage and limited outdoor advertising, year outdoor life.

MASKING TAPE

HSTM.COM [general purpose 18mm]

TYPICAL APPLICATION: General purpose packaging, bundling, holding,splicing masking and labeling for home, school and industry.

WAX PAPER

[semi-translucent]

TYPICAL APPLICATION: used in baking and cooking for its non-stick properties.

STONE SEALANT

GENKEM NOVA 2 Slasto 'n Stone Sealer [clear]

TYPICAL APPLICATION: indoor and outdoor "slasto" and porous stone sealant.

CLING FILM

[clear]

TYPICAL APPLICATION: sealing food items to keep fresh.

WOOD GLUE

HENKEL PONAL Wood Glue: extra strong [clear]

TYPICAL APPLICATION: : suitable for most types of woods and wooden materials, also bonding paper, cardboard and cork - water soluable.

ALUMINIUM FOIL

[silver]

TYPICAL APPLICATION: packaging food and other chemical products.

VASELINE [petrolium jelly]

[clear]

TYPICAL APPLICATION: skin care lotions, general lubricant [eg. rubic's cube].

8.3 COATINGS AND TREATMENTS

- FIRE RETARDANTS
- WATERPROOFING
- INSECTICIDES
- UV DEGRADATION

MOST DURABLE COMBINATION OF COATINGS

CeramiBoard®

Is a liquid mixture applied as a coating that impregnates the cardboard becoming hard on curing. It provides the cardboard with a 60 minute fire rating.

This coating increases the cardboard's strength four fold and provides excellent acoustic and thermal ratings. It is estimated that this type of cardboard can last between 20-30 years.

Product can be grounded up and recycled back into the pulping process. The this product competes with materials such as concrete, fibre cement and plaster board that can not usually be recycled.

Ceramiboard is an Australian product. They are currently in the process of commercializing the manufacturing of the product and is of yet not commercially available in South Africa.

Fire retardant additive : Morgan Paper Coaters

Morgan Paper Coaters supplies a fire retardant additive that prevents paper and cardboard products from igniting.

It is locally available yet very expensive for the quantity required for the shelter.

Intumescent coatings: Micon Intusayf

Intusayf is a water based intumescent paint that provides fire resistance to structural steel but has been successfully tested on cardboard. It has an acceptable degree of water resistance and excellent thermal insulation properties. This product is non toxic and environmentally acceptable.

It works by expanding 20 times it's applied thickness, foaming and forming an insulated foamed carbonised char that protects the surface when fire breaks out.

Timber Sealant

As an ad hoc solution some companies[1] apply a timber sealant to provide the cardboard with the neccesary waterproof properties.

1. Willemse (2009)

Polyphen

Polyphen is a plastic coating added during the manufacturing process. It is very durable indoors but would be susceptible to UV degradation when used outside.

This type of coating does not allow cardboard to be recycled into the pulping process again.

Wax Coatings

Self Adhesive Films

HydraBan®

HydraBan® is water based treatment for kraft paper. It imparts a high degree of water repellency while remaining printable and gluable.

Because this treatment is water based treated cardboard can be recycled and repulped.

The product does not increase the strength of cardboard but it enables material to retain its original structural properties under more severe circumstances.

It durability could not be determined but Nampak Corrugated[1] disclosed that they built a fish tank out of Hydraban treated cardboard that retained its integrity for more than a week. It does however remain an expensive product.

1. Van Lingin (2008)

VaporCoat®

VaporCoat® is a recyclable water-based moisture barrier coating for corrugated cardboard and paper. The product protects the substrate from water whilst allowing the transmission of water vapour. VaporCoat® can replace costly, non-recyclable curtain coating, poly-laminated linerboard and plastic bags in many applications.

This coating also provides excellent grease resistance.

Vapourcoat is sold by Morgan Paper Coaters, Durban and costs the same as Hydraban.

Although these products are not made locally they both Hydraban and VaporCoat are commercially available in South Africa.

MOST SUSTAINABLE

Boric Acid

Boric acid is an organic compound of boron. It is a water soluable powder that can be added during the pulping process or as an spray on coating.

Boric acid is commonly used as an ingredient in insecticides for agricultural purposes as well as domestic. It is also applied to cellulose insulation as a fire retardant and insecticide.

Experiments have proven that a 8% solution would suffice for the purposes of the shelter.

Sugarcane Lignin

Australian chemists[1] have developed a new waterproof coating from sugarcane lignin (the organic component that gives the sugarcane plant its structural strength). This new development could potentially replace conventional coatings such as wax and plastic.

This new coating is completely recyclable and can be reused in the pulping process to produce recycled paper. Although not commercially available the product has had very promising test results.

1. ANI (2008:[1of1])

BreatheCoat

BreatheCoat is a paint that uses a membrane technology to prevent water from coming in but allows vapour to pass through.

It is a water based paint that requires no under coat and can be painted on wet surfaces. The product is solvent free, nontoxic and environmentally friendly.

Because BreatheCoat paint is supplied in powder form it is easy to transport and can therefor be applied after assembly to extend the life span of the shelter.

CORRUGATED CARDBOARD PROFILE

The basic corrugated sheet consists of two linerboard facings and a corrugated medium (flute)

The liners are usually made from natural kraft (light brown) but bleached kraft is also used (mottled/ white).

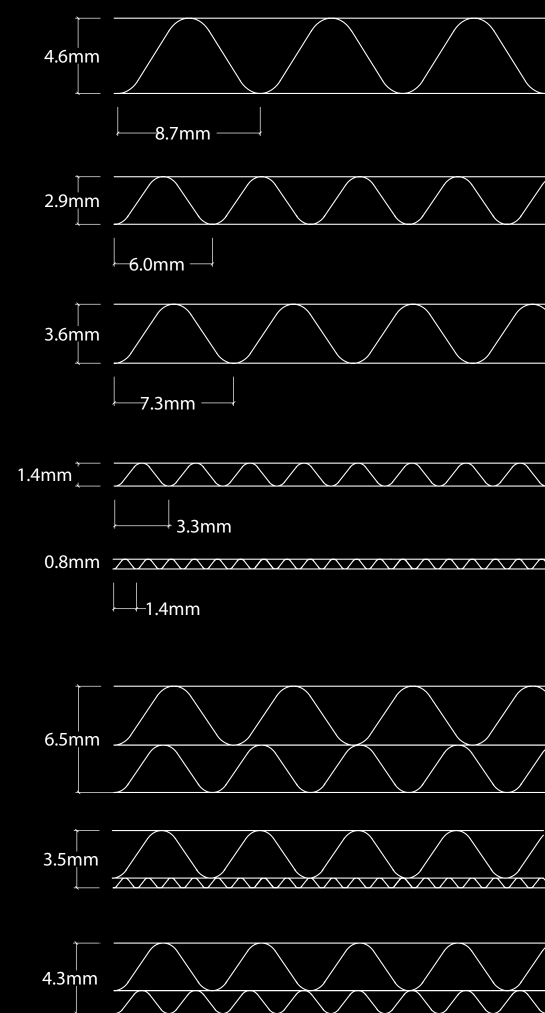


Figure 184 The various corrugated cardboard profiles

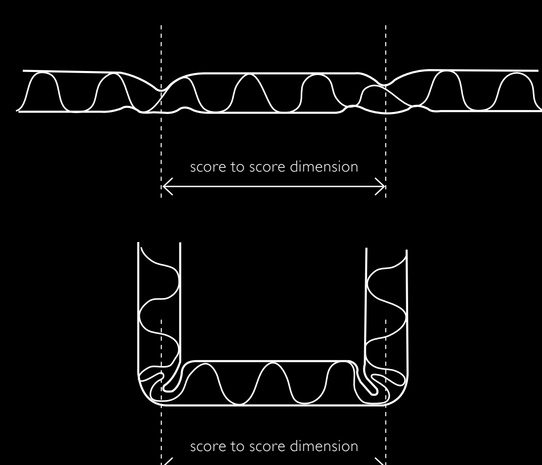


Figure 185 Scoring allowances **:** Kelsey, Forcinio & Hanlon (2005:466) are based on the thickness (caliper) of the corrugated board. *To achieve the given interior dimention the score dimentions should be one thickness farther apart to account for 'inside gain' and 'outside loss'. When the board is folded on the score lines, the scoring dimention fall in the center of the wall.*

FLUTES

Flutes are named in the order of their invention and not according to their size.

A - flute : the original flute and has the highest arch height. Excellent stiffness and short column crush resistance and is most widely used for its cushioning properties.

B - flute : good all round compression strength, compactness, printability and cost effectiveness. Also handles complex die cuts very well.

C - flute : larger than B but smaller than A. It is by far the most commonly used flute type with an estimated[1] 80% of the worlds containers made of C flute cardboard. Although it has greater compression strength but can be more easily crushed.

E - flute : fine flute that provides excellent crush resistance and printability.

F - flute : is just over half the thickness of the E - flute. It is the newest addition to the packaging industry and offers the lowest fibre content of all the other flutes.

BC - flute [double wall] : the combination of B and C flutes offers greater compression and stacking strength.

EB - flute [double wall] : the combination of E and B flutes merging the good compression strength of the B flute with the crush resistance of the E flute with excellent printability. It takes up less space than the EB profile.

BF - flute [double wall] : very strong crush resistance and rigidity as well as excellent printability. It has the lowest combined fibre content of all the double wall profiles, yet remains one of the most expensive.

1 Enviroman (2003:[1of1])

Figure 186 Folded concept model

8.4 LANGUAGE

To successfully posit cardboard in the field of architecture, cardboards requires its own language. One can therefor ask this humble material what it wants to be and Cardboard answers: *Fold me I want to be strong.*

Folding in principle can be approached in a qualitative and a quantitative sense. This project draws inspiration from both.

8.5 FOLDING

8.5.1 MORPHOGENETIC PROCESS

In architecture folding is a **morphogenetic process.** It is generative and essentially experimental.

"Folding[17] is not concerned with creating a new style but rather with searching for links". It is not a linear process, every fold allows you to retrace your steps, every step is a test or exploration of unknown possibilities, becoming a 'map of its origination process'.

In order to progress one has to make choices, therefore within the limitations of folding also lies its innovation.

The fold is more intrinsic than origami as it excludes the logic of the narrative in favour of associative coherence, a language for design. Yet origami remains a powerful tool in analyzing, understanding and manipulating the fold, once the desired pattern has been developed during the experimental process.

To conclude Vyzoviti[18] suggests that: "...we can appreciate the function of folding as a design generator by phase transitions, that is, critical thresholds where qualitative transformations occur."

This view can be adapted and interpreted directly to the problem statement:

We can appreciate the function of ***design*** as a generator of phase transitions, that is, critical thresholds where qualitative transformations occur ***within the long term post disaster relief operations.***

8.5.2 PRINCIPLES OF ORIGAMI

It's just a mater of math. In Lang's opinion[19] someday "all the myriad components of a building might be made from the same simple sheets, folded in myriad ways."

Origami is the Japanese art of paper folding, only one sheet (a square) and no cuts. Kirigami works in a similar way except that small cuts are allowed in the process of folding. Origami revolves around crease patterns. Lang suggests that there are four basic laws that allows one to fold just about anything: using math and engineering principles with the help of advanced computer technology. These 'laws' according to Lang[20] are:

(1) Crease pattern properties

2 colourability: any crease pattern can be colored with just two colours, without the same colour meeting

(2) Mountain valley counting

at any interior vertex M-V = +/- 2: at any vertex the number of valley folds and the number of mountain folds will always differ by 2 [either two less or 2 more]

(3) Angles around a vertex

if you number the angles around a fold in a circle, all the odd numbered angles will add up to 180° and all the even numbered angles will add up to 180°

(4) Layer ordering no self-intersection at overlaps

no matter how folds and sheets are stacked - a sheet can never penetrate a fold

16 Fletcher (2001)
17 Vyzoviti (2006:6)
18 Vyzoviti (2006:8)
19 Holland (2009:27)
20 TEDtalks (2008)

"To express is to drive.

And when you want to give something presence,

you have to consult nature.

And there is where Design comes in.

And if you think of Brick, for instance,

and you say to Brick,

'What do you want Brick?'

And Brick says to you

'I like an Arch.'

And if you say to Brick

'Look, arches are expensive,

and I can use a concrete lentil over you.

What do you think of that?'

'Brick?'

Brick says:

'... I like an Arch'"

: Louis Kahn[1]

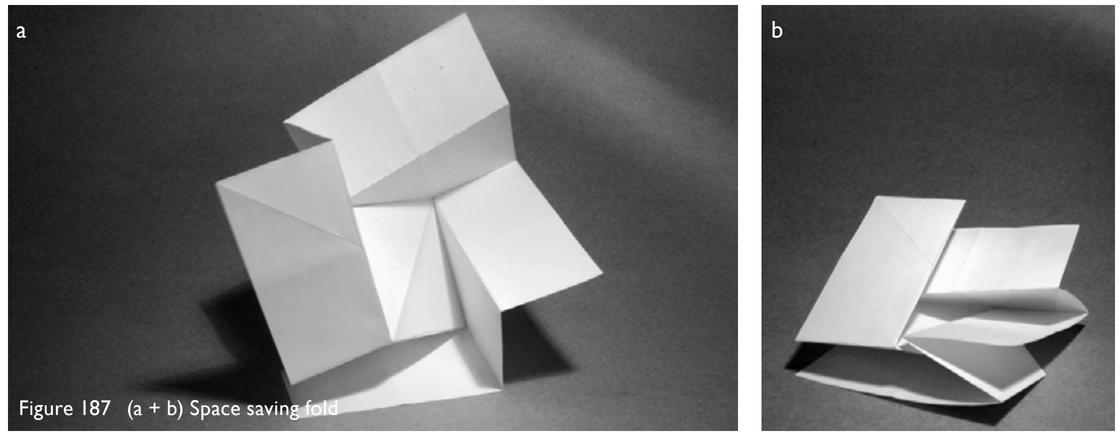


Figure 187 (a + b) Space saving fold

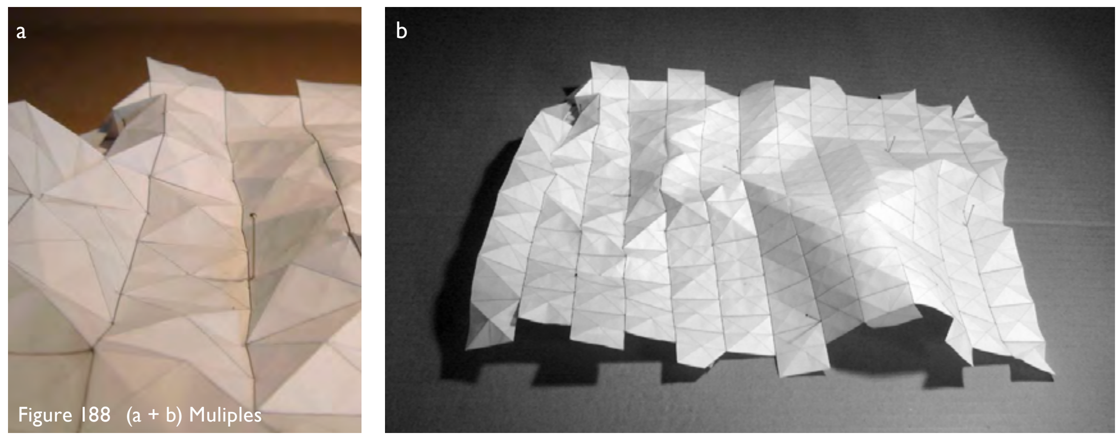


Figure 188 (a + b) Muliples

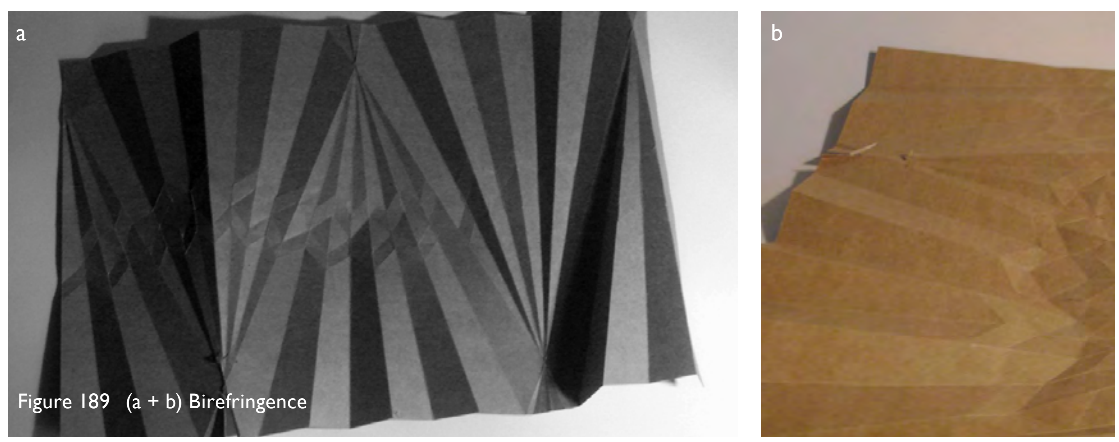


Figure 189 (a + b) Birefringence

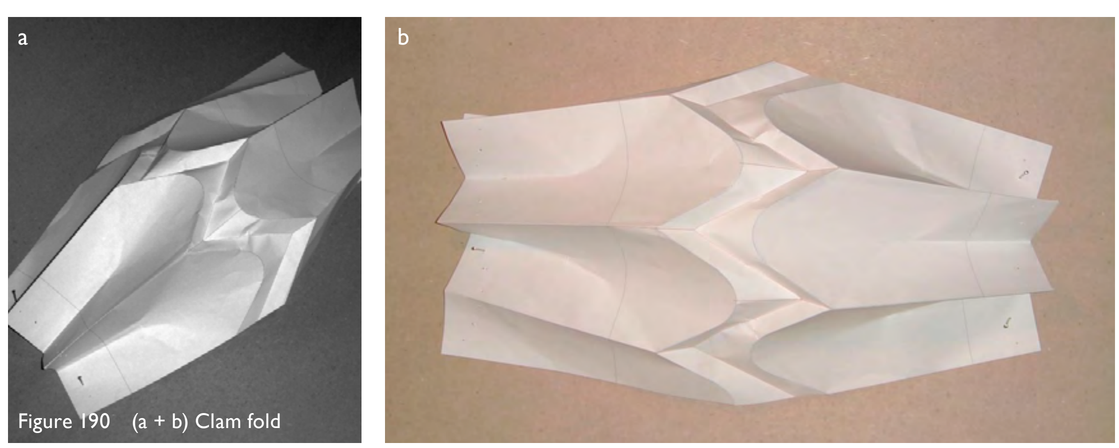


Figure 190 (a + b) Clam fold

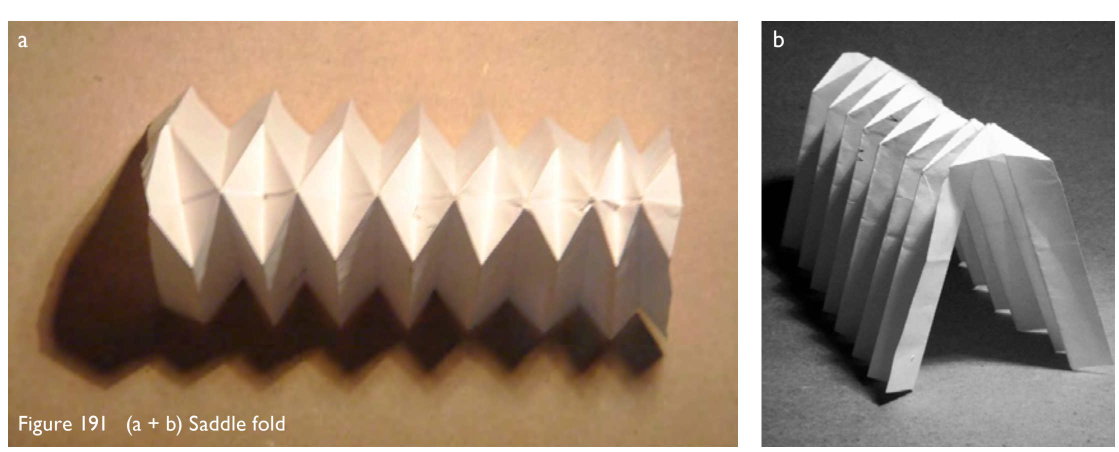


Figure 191 (a + b) Saddle fold