HUYS ADVIES

A-Frame School Chair Design

Strong (Timber) School Chair for
Schools Not Yet Adequately Seismically Strengthened

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Title: A-Frame School Chair Design. Strong (Timber) School Chair for Schools Not Yet Adequately Seismically Strengthened

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Abstract: Simple design of an easy-to-manufacture timber school chair which is strong enough to withstand the heavy weight of a collapsed concrete or soil roof caused by an earthquake. The symmetrical A-frame design is based on an earlier more vertical design and has angled sides for additional stability. Normal timber and multiplex are used, with all connections glued and screwed together. The cores for the thin screws are pre-drilled to avoid splitting of the timber. Four ergonometric chair sizes are recommended to accommodate the various heights of schoolchildren at different ages. The "Drop, Cover and Hold On" principle is currently being promoted as a safety measurement during earthquakes to prevent injury from broken glass and falling suspended ceilings. However, flimsy chairs and tables will not provide protection against collapsing upper floors. Having a few dozen of these strong chairs in each classroom will support the collapsing heavy roofs, providing a safety space and allowing escape from the rubble afterwards.

Key Words: School furniture, strong chairs, earthquake, timber, A-frame, ergonometric, local manufacture.

Background: During the past 40 years, the author has worked for DGIS (Ministry of Foreign Affairs of The Netherlands) and INGOs and (including UNCHS, UNESCO, ILO and AKDN) on many practical and product-focussed development programmes in developing countries worldwide. The projects and programmes were output-oriented with well-defined educational objectives and many were related to settlement upgrading, housing and school building improvement, and entrepreneur development. In several South American and Asian countries, the author was involved in earthquake-resistant housing and school design, retrofitting and related subjects.

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Photo Front Page
Model A-frame chair with timber frame and multiplex seat and seat supports.
Further development can be the shaping of the lower side of the back support or a shaped seat.

INTRODUCTION

While working for UNESCO in 1971-1974, an easy-to-manufacture timber school chair was redesigned, replicated and promoted as a low-cost, sturdy piece of furniture.[1] The design had straight timber planks of only two sections (2 x 8 cm and 2 x 18 cm). Stability of the chair was achieved by its A-frame. Different ergonometric sizes were produced to accommodate different children heights. Self-assembly by students would lower transport and manufacturing costs.

In 1998, I reintroduced a similar model in the Northern Areas of Pakistan, which was replicated by local carpenters using good quality locally available pine wood. Alternatively, the slow growing poplar wood could be used, also in abundance in the higher altitude regions.

Pakistan is a high-risk earthquake area. The towns of Muzaffarabad and Balakot were devastated by an earthquake (Richter Mw 6.7) on 8 October 2005. Thousands of schoolchildren perished due to very unstable and heavy school building designs constructed during the former century. Almost the entire primary school population died when the heavy dressed stone walls and roofs of the government schools collapsed. Flimsy metal tube school furniture did not support any significant load, while the youngest children were sitting on mats only, with no furniture in the classrooms.

The general principle currently being widely promoted to minimise risk and injury to schoolchildren is: "Duck, Cover and Hold On". Especially in schools with large glass windows, suspended ceilings and tube lights or lamp fittings in the ceiling, this strategy will protect the children from falling ceiling panels, insulation materials, piping, etc., which may shake loose during a prolonged earthquake. However, many rural schools do not have suspended ceilings, but still have very heavy roof structures with soil cover, prefabricated concrete beams with cement block infill, or reinforced concrete floors on loosely built stone walls.

Photo from Geohazards International promotion leaflet: GHS brochure, India (www.geohaz.org).

For all single storey schools (ground floor only) being of heavy and deficient building construction, the children should be educated, trained and conditioned to vacate the building immediately and wait outside. The escape routes should be wide and all doors (preferably double) should easily open outwards to avoid any obstruction.

When an immediate ground floor escape is not possible and the collapse of a heavy roof can occur during a prolonged earthquake, the only chance of survival is to follow the "Drop, Cover and Hold On" principle, provided the furniture will hold up. The latter is seldom the case because in many rural schools the furniture budget is one of the smallest and invariably the cheapest supplier is contracted. The furniture is then of poor quality with a short life cycle. Often piles of abandoned benches and chairs can be found in older schools. When lightweight plastic furniture is used in the classroom, it will easily crush with several tons of stone or concrete mass coming down, in which case the "Drop, Cover and Hold On" principle will provide little protection to the children.

Internet photo left: Modern school furniture is often lightweight with the use of plastic.

Internet photo right: In some low-income areas, the mass produced all plastic chairs are being used in the schools.

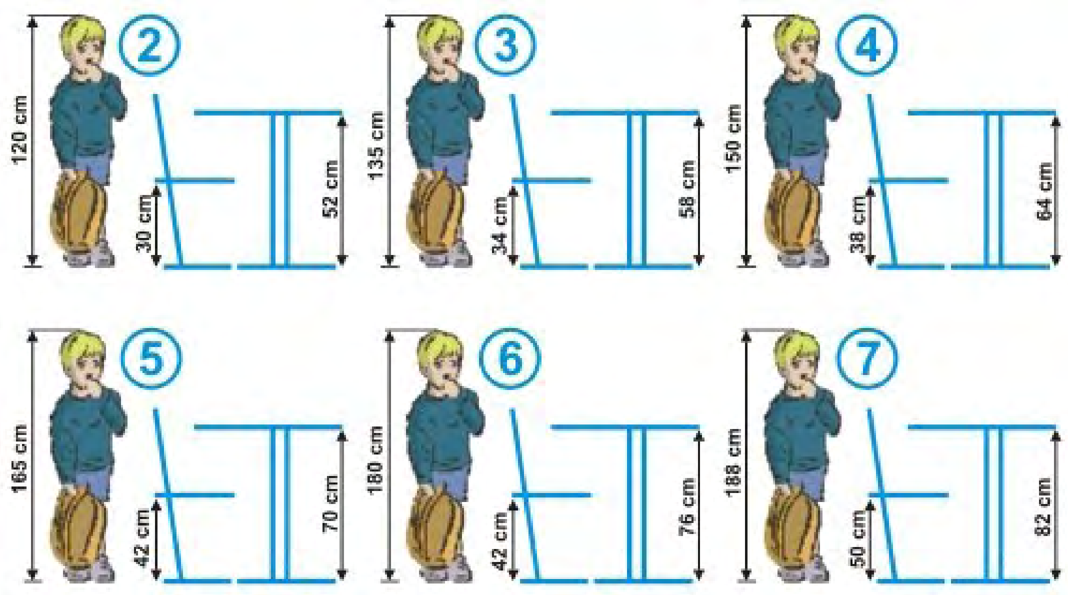
[1] The original foldable design was developed by J. Gammelgaard of the Regional Educational Building Institute for Africa (REBIA). The Asian Regional Institute for School Building Research in Colombo, Sri Lanka, improved the design and published Technical Note # 7/1972 on both chair and table.

Many school buildings have not yet been seismically strengthened (retrofitted) because of the high cost, potentially exposing the occupants to earthquake disaster.[2] Considering the above, the original timber A-frame chair design has been slightly modified to make it even stronger and more resistant against a side load.

Some schools do have sturdy timber furniture, such as shown in the photo right. However, having the seat attached to the inclined table does not allow much flexibility of space use other than a row of benches behind one another.

> *The seats and table tops of the furniture are too small for the students. The amount of timber required to manufacture the designs proposed in this paper is no more than that used in making the pictured furniture.*

For good education, the sitting position of the students should be optimised and adjusted to their anthropometric dimensions. The tables should be versatile to allow grouping in lines, squares or clusters for different educational activities and settings. Inclined table tops do not allow grouping or the creation of larger, flat working surfaces.



Example of anthropometric school furniture dimensions from a Japanese Internet site.
The A-frame chair in this paper regards <u>four different heights</u> as being adequate.

Only the largest chair has been detailed in this paper. However, the three other chairs sizes are proportionally smaller, with the exception of the timber cross sections. In a single classroom, different chairs sizes are possible to suit different age groups and/or growth differences. Equally, the table heights need to be related to the anthropometric sizes of the students. The tables can also be made strong, proving additional safety in the event of a large earthquake.

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[2] In many cases, the first earthquake impact is very violent and does not allow the students time to evacuate the building, even if the classroom is situated on the ground floor and with large doors opening to the outside.

DESIGN PARAMETERS

Load and Impact. The design can be replicated using steel tube or other material that can withstand a great impact and carry a considerable load. The design is based on the idea that a classroom has at least 20 chairs or about one chair per m^2 floor surface. All chairs will need to be able to carry at least 1 m^2 floor or roof weight.

A reinforced concrete floor of minimum 12 cm plus a covering can be as thick as 18 cm together. Such a roof has a weight of approximately 0.18 m x 2200 $kg/m^3 \approx 400$ kg/m^2. Thus, the chair (or chair with table) should be able to carry or withstand a load of approximately 500 kg. For many school buildings, this means that strong chairs, preferably along with strong tables, will be required as long as these schools have not been retrofitted.

There is little chance of survival if the heavy concrete floors collapse or the building pancakes.

The total section of the four inclined chair legs is 48 cm^2. Good pine timber has a maximum compressive strength parallel to the grain of about 20 $N/mm^2 \approx 200$ kg/cm^2. This means that the A-frame chair can support a vertical load of about 600 kg. In this case, the multiplex seat connections should be able to support about 100 kg load horizontally.

Testing. It is recommended that the selected design be tested on total load resistance and labelled with that information. Different timber types and sections will make a strength difference.

Dry Timber. The timber used to make the chairs should be adequately cured so it has stopped shrinking, warping or cracking, and have a humidity level below 12%, preferably as low as 8%.

Glue and Screws. When the manufacturer skimps on the PVA synthetic wood glue and does not pre-drill the cores for the screws in the timber pieces, the furniture will not be strong enough to withstand continuous rough treatment by the students.

Jigs. Each manufacturer needs to make jigs for fast sawing, drilling and assembly of large series of chairs to keep the production line efficient and low-cost. Assembly jigs can be lent out to the schools.

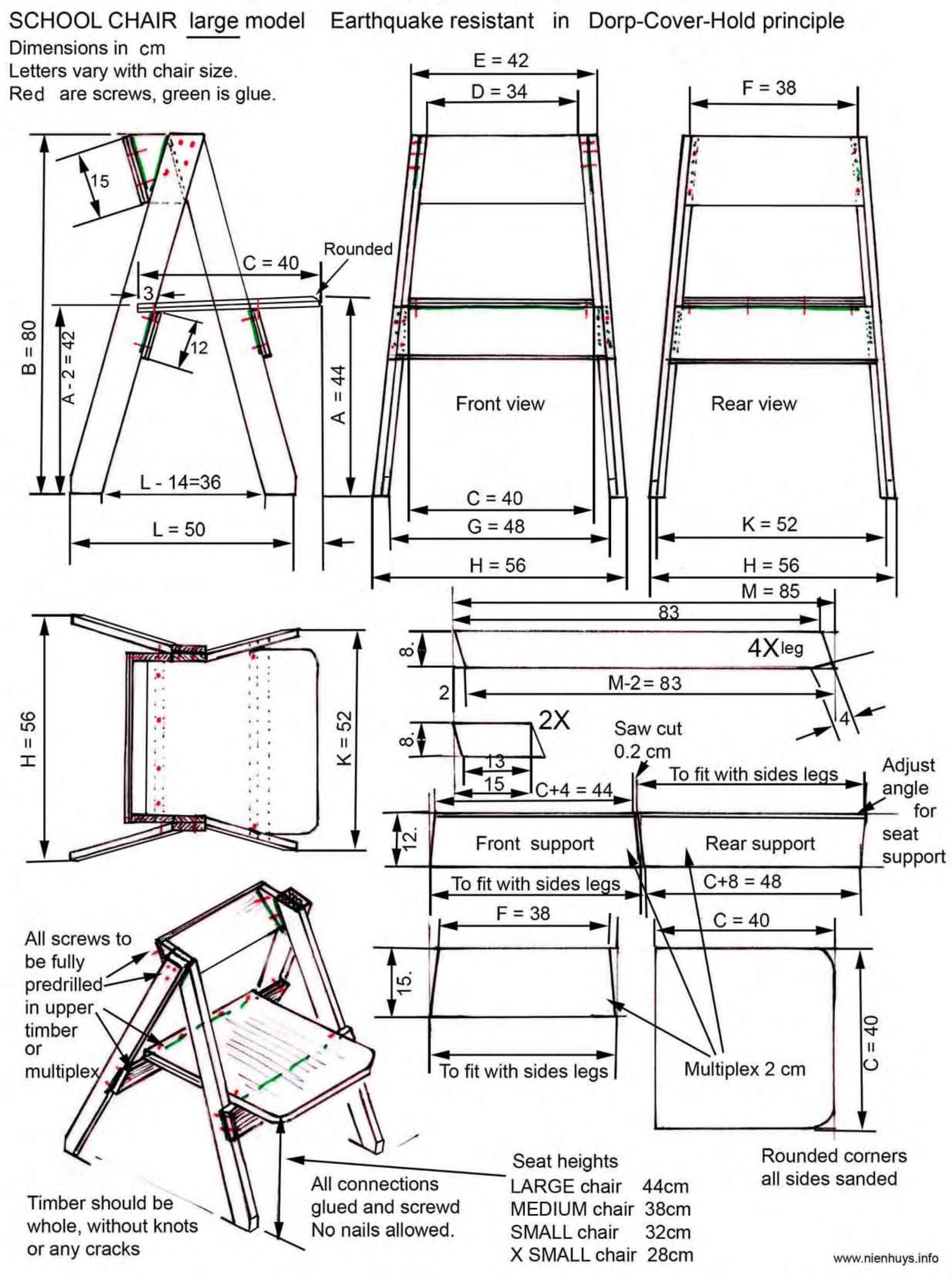
Timber and Multiplex or Plywood. The vertical A-frame members are from timber, while the horizontal members (especially the seat) are made from multiplex (20 mm or thicker). Water-resistant quality multiplex is recommended for durability. The sides need to be sealed.

Rounding and Sanding. All sides of the timber and multiplex should be bevelled, rounded and sanded to avoid any possible damage to clothing worn by the users. The bottom of the legs need special attention depending on the surface they are going to be used on and should be well chamfered to avoid splintering when being dragged over the floor.

Colour Coded. The four different chair heights can be colour coded for easy reference. Only the top of the A-frame needs to be coloured. For example, the **Large** chair with a **Brown** top, **Medium** chair with a **Blue** top, **Small** chair with a **Green** top, and the **Extra Small** chair with a **Red** top. This way it is easy to tell a student to get a chair of another colour.

Finishing and Maintenance. There is seldom maintenance-free equipment. Giving the chairs a coat of varnish, paint or other coating will make them more presentable. Although painting will substantially increase their unit cost, this can be undertaken at the school by the students as a self-help project and thereby reduce the cost.

DESIGN OF THE LARGE CHAIR



Timber can also be 70 x 22 mm section. Multiplex is minimum 20 mm thick. The manufacturer should verify all dimensions on the basis of a prototype and set the machines for the most efficient series production using manufacturing, drilling and assembly jigs.

Side View

Half Side View

Front View

← Rear View

→ The different parts of the chair with pre-drilled holes for sunken screws, 26 screws and PVA glue.

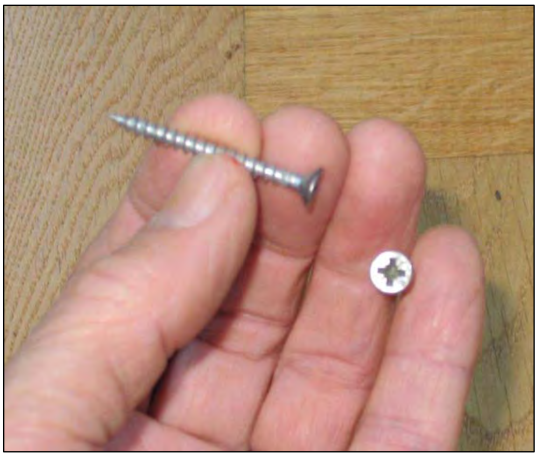
Packaging in sets with a self-assembly instruction will keep the purchase and transport costs low.

The timber screws are preferably thin (such as the pictured 3.5 mm x 40 mm) and threaded the whole length. This screw requires pre-drilling the core of the screw to avoid splitting of the timber. The pre-drilling diameter of this screw is 2.0 mm.

For the top of the chair, the screw holes should be minimum one timber thickness away from the top.

The use of Phillips (+) screws is practical for both electric powered tools and hand tools as slipping is minimized.

Self-tapping gypsum board screws, chipboard screws or fibreboard screws are unsuitable.



The timber screws are principally to ensure that the gluing is well fixed and the timber pressed together during the drying. Only dry timber can be properly glued this way. When the furniture is to be used <u>outdoors, water-resistant glue should be used</u> instead.

QUALITY CONTROL IN MANUFACTURING

The timber A-frame chair becomes economical when manufactured in large series and with the use of appropriate mechanized woodworking equipment. Cutting the pieces to their required length or dimensions (multiplex) requires making precise jigs. Equally, for the vertical drilling of the cores for the screws, jigs and templates are highly recommended, if not essential. The following aspects of the quality control are important:

(a) Timber for the legs should be without any well defined or hard knots, warping or split sections. In addition, soft knots are not allowed because over time these will dry and cause weakness. Pit-knots smaller than 10 mm are allowed, provided these are not along the two long, narrow sides of the planks.

(b) Timber for legs should have a humidity of 12% or less. When the furniture is going to be used in heated rooms, the humidity may not be more than 8%; otherwise shrinkage will occur over time. Softwoods such as pine or poplar are subject to shrinkage when not well dried.

(c) The short planks to fit the back support should be factory glued to the top of the legs. High strength water-resistant PVA glue should be used for this connection.

(d) All sides of the finished timber and multiplex should be chamfered about 1-2 mm. The multiplex seat needs to be well rounded at the knee side and sanded smooth.

(e) All multiplex should be sealed around and in between any open layers (if these are present), filled with glue and sanded smooth.

(f) The core of the 3.5 mm screws (2.0 mm) should be pre-drilled in all timber and multiplex. Drilling jigs should be made in which the legs and other elements are laid out to ensure precise drilling. Free-hand drilling is imprecise and usually crooked.

(g) The drilling needs to be perpendicular on the surface of the element, except for the 6 holes in the long sides on the two seat supports. The screws through the seat are to be vertical. The distance of the screw holes from the end of the leg should be minimum the timber thickness.

(h) The screw holes in the multiplex elements (seat, seat supports and back support) need to be sunken just enough to avoid that the flat head screws protrude. Only the screw holes in the top sides of the seat supports are not sunken because these are covered by the seat.

(i) Screws supplied have a length of double the timber thickness. When the timber is 20 mm, the screws should not be longer than 40 mm. The screws need to be galvanised.[3] Protruding screws should be sanded off after assembly has been done.

(j) Timber screws with a thread over the whole length should be used. Timber screws with Phillips (+) head grooves are preferred to avoid slipping of the (electric power) screwdriver. Thin screws (3.5 mm x 40 mm) are recommended. Pre-drill with 2.0 mm.

(k) Synthetic timber glue should be of good quality and allow complete drying in 24 hours after application. PVA = PolyVinylAcetaat dries by evaporation of the incorporated water. Chairs that are exclusively for inside use can be manufactured with this type of glue. Chairs that are also required for outdoor use need water-resistant PVA glue.[4] Large glue containers should be avoided since these usually result in large amounts of wastage.

(l) The manufacturer should supply a picture checklist of all the chair elements in the package (timber, multiplex, screws and glue). The timber humidity and the glue quality (normal or water-resistant PVA) should be indicated on the package.

[3] Stainless steel screws are also available, but these are more expensive.
[4] Water-resistant glue is stronger than normal PVA, but is more expensive. The manufacturer needs to supply the option of water-resistant glue for schools that will use the chairs outdoors.

FOUR DIFFERENT CHAIR HEIGHTS

The body lengths of schoolchildren vary and therefore different sitting heights are required based on the length of their legs below the knee. This length is approximately 26% of the total body height including the shoe sole. For example, if a person has a body length of about 170 cm, 26% of this height equals 44 cm; being the sitting height of the **Large** chair. This sitting height will be about the same when the seat is only slightly declined towards the rear (2 cm). Declining the seat slightly towards the front makes the chair uncomfortable.

It would be too costly and inefficient to make too many different chair heights. For that reason only four heights have been chosen with intervals of 4 cm to 6 cm each. The following table is a guideline for the range of four chairs. Dimensions are approximate. The manufacturer needs to make prototypes before series production by machine.

Description	**Brown**	**Blue**	**Green**	**Red**
Average age group	Over 15 years	12 – 15 years	8 – 11 years	5 – 7 years
Full body length	160 - 180 cm	140 – 155 cm	120 – 135 cm	105 – 115 cm
Dimensions of pieces				
A. Sitting height 0.26 h	44 cm	38 cm	32 cm	28 cm
B. Top of chair	80 cm	70 cm	60 cm	50 cm
C. Seat dimension	40 x 40 cm	36 x 36 cm	34 x 34 cm	32 x 32 cm
D. Inside top	34 cm	31 cm	30 cm	29 cm
E. Outside top	42 cm	39 cm	38 cm	37 cm
F. In between top	38 cm	35 cm	34 cm	33 cm
G. Between front legs	48 cm	43 cm	41 cm	39 cm
H. Outside rear legs	56 cm	51 cm	49 cm	47 cm
K. Inside rear legs	52 cm	47 cm	42 cm	43 cm
L. Front legs to rear legs	50 cm	45 cm	40 cm	35 cm
M. Length of legs	85 cm	75 cm	65 cm	55 cm
Multiplex thickness	20 mm	20 mm	20 mm	20 mm
Timber sections	8 x 2 cm	7.5 x 2 cm	7 x 2 cm	6.5 x 2 cm
26 galvanised timber screws, 3.5 x 40 mm, suitable for electric screw driver (+ top groove).	8 screws to assemble legs together (2 pairs), not similar, use jig. 8 screws to assemble seat supports to legs; use jig. 6 screws to assemble seat to seat supports (2 in front, 4 in rear). 4 screws to assemble back support to the legs.			

Using 70 x 22 mm section timber will change the sizes slightly.

Assemble-It-Yourself at the School

The purchase cost of the furniture can be substantially lowered if all the pieces are pre-cut and pre-drilled, and the assembly (gluing and screwing) is done at the school, for example by the students. The lower costs will be related to no assembly cost in the factory and reduced transport volume; thereby lowering transport cost. By packaging the elements together, less transport damage will occur.

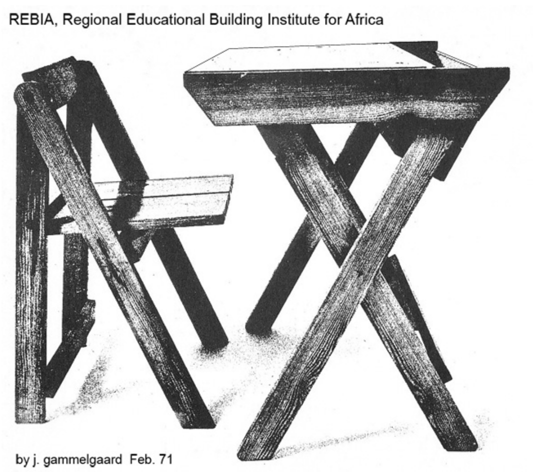
When dealing with large quantities, the manufacturer could supply or lend out assembly jigs and tools; one flat jig for making the A-frame and another in which the assembled A-frame is placed on its side for attaching the seat supports and back support. The jigs and tools can be obtained on a loan basis from the manufacturer and returned when the assembly is completed.

Further Testing and Development

Testing can produce data for further strengthening. Elements such as inclination and timber (or steel) sections can possibly be improved upon. Cost analysis should determine which material would be the most cost effective. Similarly strong tables can be developed.

ANNEXE I: REBIA CHAIR, SUDAN, 1971

The foldable chair and table pictured were developed by the Regional Educational Building Institute for Africa (REBIA) for classrooms in the Sudan.



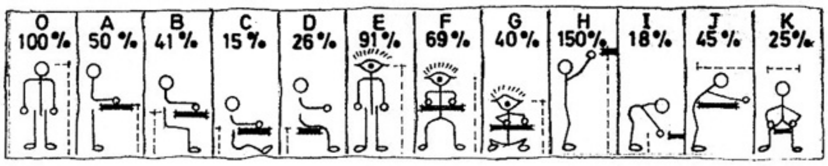
This furniture design was based on anthropometric measurements of schoolchildren in a Sudanese village and averaged per body height group.

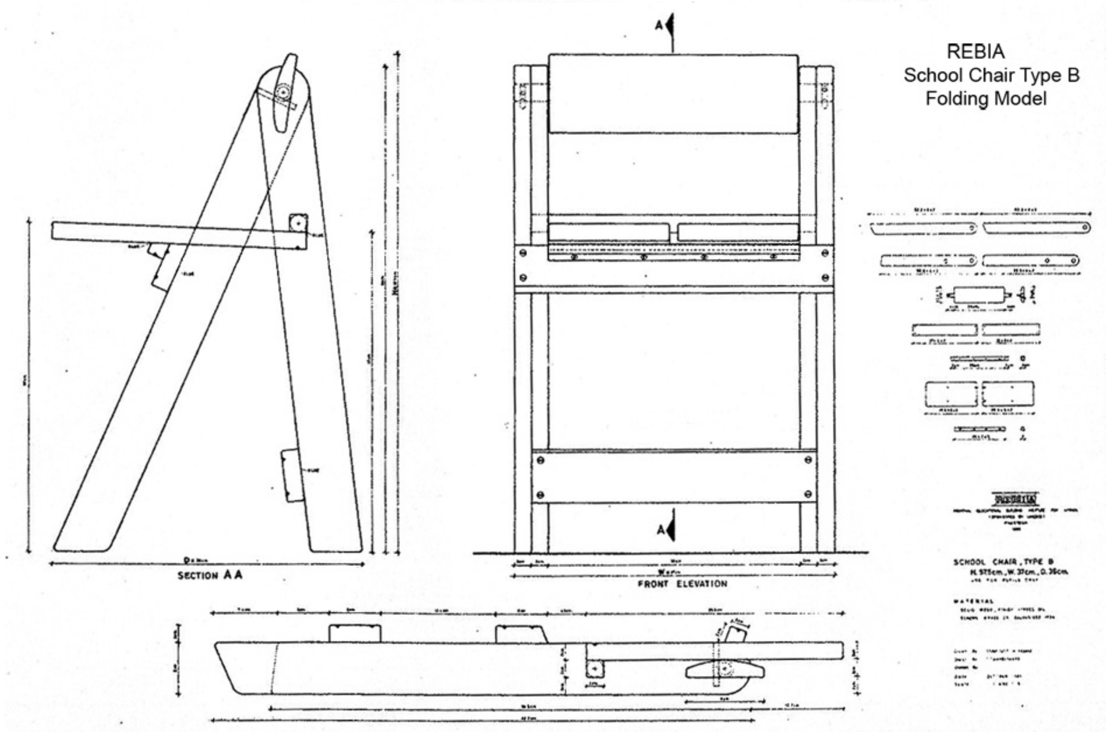
Boys and girls have different heights within the same age group. Instead of having only one height of furniture in the same classroom, several heights can accommodate the different body sizes of the students. The anthropometric height percentages are resumed in the chart below.

This table is fitted with a box in the rear for storing books and can be adjusted in height to match the chairs. The box limits multiple use.

The Sudan had already by 1970 a severe lack of timber. All timber and steel needed to be imported, two drawbacks of any furniture design. Plastic chairs did not exist.

Guide for the establishment of standard size school furniture, when no anthropometric data are available.





The folding designs were difficult to make and lacked durable stability. Making several fixed table designs was cheaper than making the adjustable table. In a later version, the chair was also made as a fixed model in which the lower cross connection between the legs was omitted.

ANNEXE II: BREDA-UNESCO CHAIR 1972

When working with the “Bureau Regional de l’Education en Afrique” (BREDA) of UNESCO in Dakar, Senegal, I developed audio-visual material for the promotion of the timber A-frame chair which was earlier developed by UNESCO in Beirut. The pictures below are from one of the slide series.

FIRST. The comfortable furniture height is related to the child’s standing height

If the chair is to be comfortable, we must know the body sizes of the users.


Because the seat height is always 1/4 from the standing height, children of different ages need chairs of different sizes.

Only the standing height needs to be measured because the size of all other body parts bear a constant relation to it.


Construction is simple.
All timber is the same thickness and width and only two widths are used.


Joints made with PVA glue and screws remain strong, even if timber shrinks.


And we have avoided joints like this one that may work loose.


Assembly by the students

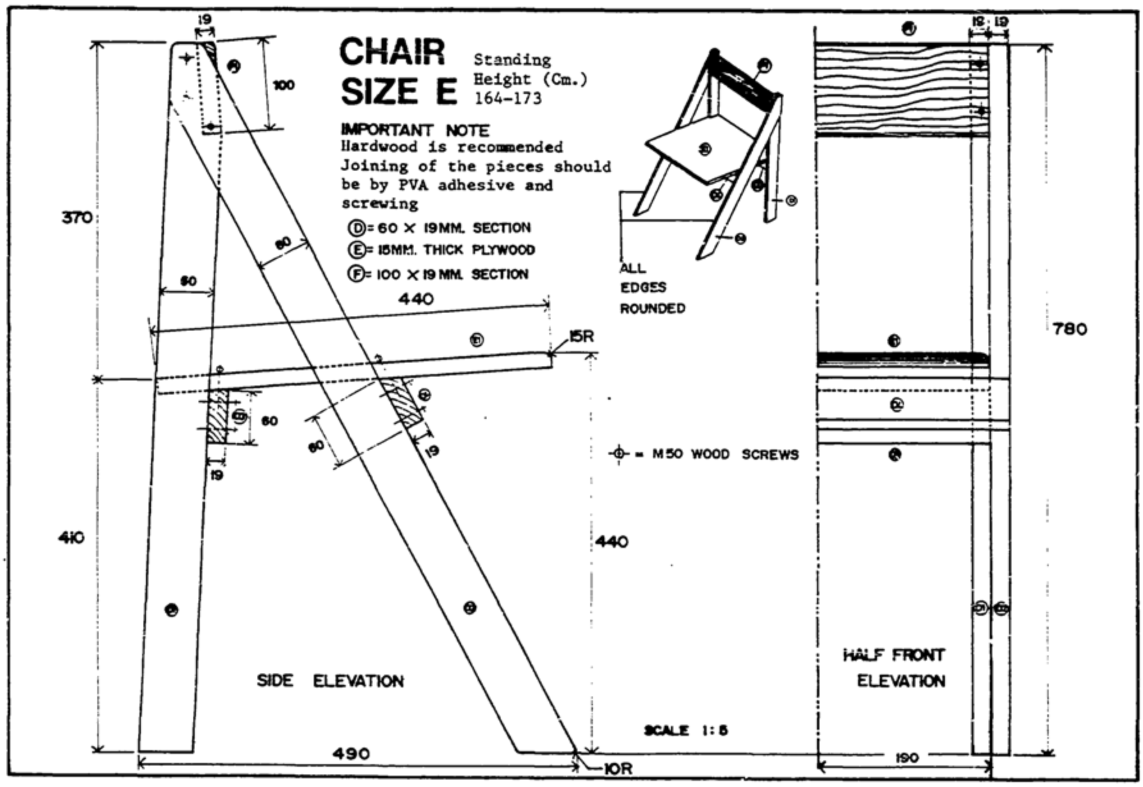
Table top is 2/5 of standing height

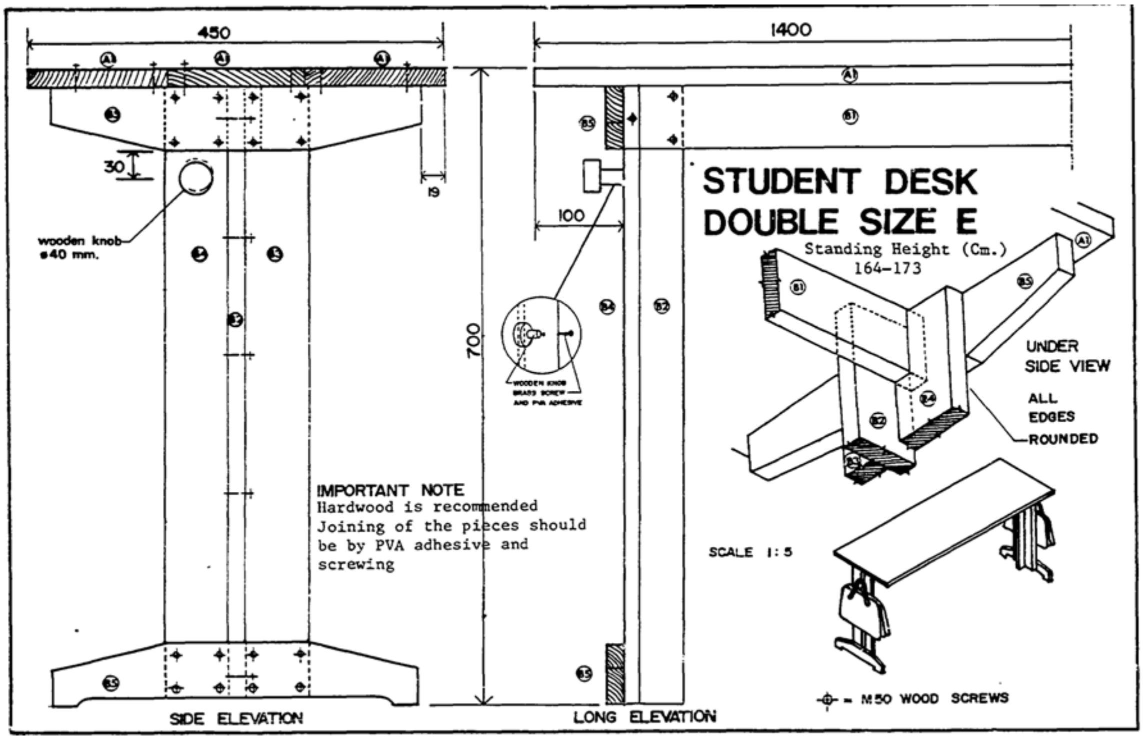
Some schools in West Africa adopted the design, but widespread replication was not evident and I am unaware of any follow-up. Heads of schools would rather wait until their ministry supplied the furniture or purchased the cheapest equipment without being involved in either the design or manufacturing. The back support in this chair has a rather forward position.

The new A-frame chair proposed in this paper has a better position of the back support and stronger seat connections than the original BREDA-UNESCO chair. The back support is now one piece and does not require shaping. Because the seat is also one piece of multiplex, the A-frame chair is stronger and more durable.

ANNEXE III: UNESCO REPRINT SERIES E8, 1991

Classroom Furniture Made of Wood. UNESCO Principal Regional Office for Asia and the Pacific, Educational Facilities Development Services. This design came in five heights A – E. The same document also provides details for desks and chairs in five different heights (A-E).





ANNEXE IV: BACIP CHAIR 1998

When working with the Building and Construction Improvement Programme (BACIP) of the Aga Khan Development Network (AKDN) in Pakistan, I modified and introduced the A-frame chair for local manufacturing. In the Himalaya region of the project area, there was very good quality pine timber locally available, as well as many skilled carpenters with suitable equipment. Transport of bulky furniture to the remote mountain villages was costly and the self-assembly method was a new option the BACIP programme was promoting.

However, most of the schools preferred to wait until readymade furniture was supplied from the government or received as donation from NGOs. In the interim, having no budget to purchase (new) furniture, many schoolchildren were sitting on floor mats.

Piles of broken furniture in the back of a classroom. Usually the bench is connected to an inclined table top.

This type of timber furniture is made with a double mortise joint in all leg connections; the connections being very weak.

When one connection breaks, usually the entire furniture breaks and becomes unusable. When loaded vertically on the rear support of a loose chair, the chair falls backwards.

Four chair sizes were developed with straight legs in the rear. The back support is shaped to increase the sitting comfort when leaning back.

The top of the legs were later painted different colours to easily distinguish the sizes.

By making the seat supports and back support wider, the chairs become even more stronger.

← The BACIP school chair, easily supporting five adults standing on the seat.

→ Local carpenter who manufactured a similar design for households and the village organisation.[5]

Having a single multiplex seat makes the chair much stronger than the design with two planks. Painting the chairs was optional and could be done by the students or a villager.

[5] Photos by the author. Author with carpenter and architect consultant Gulam Saeed (photo right).

ANNEXE V: "DROP, COVER AND HOLD ON"

With the disaster of the Kashmir (Muzaffarabad and Balakot) earthquake on 8 October 2005, it became clear that the flimsy steel tube school furniture did not provide any protection from falling roofs when the students were unable to escape quickly enough from the classrooms.

Many government schools collapsed in the 2005 Kashmir earthquake due to poor school design and heavy materials. Thousands of schoolchildren died under the heavy rubble from failing roof structures.

The flimsy school furniture could not support any significant load and was totally flattened.[6]

www.dropcoverholdon.org

Because the "Drop, Cover and Hold On" earthquake safety measurement is now more widely recognised and promoted, having sturdy furniture in the still unsafe classrooms becomes an important issue.

The "Drop, Cover and Hold On" earthquake safety measurement has been introduced to protect people from falling objects such as glass, ceiling panels, lamps, furniture and objects on shelves. The most practical cover is under a table, but most tables will not protect the people under it when heavy upper floors or roofs collapse.

In non-earthquake-resistant buildings, collapsing upper floors will usually lead to the death of the occupants. However, when firm elements (such as strong cabinets, tables and chairs) can withstand heavy loads and space underneath is created, people can survive until they are rescued.

← Photo from www.shakeout.org training activity

→ Photo from www.usgs.gov-images

Not all schools will be adequately retrofitted or seismically reinforced up to the recommended standards and therefore other measurements are required to mitigate the possible disaster from collapsing structures. Because the back of the chair is the highest element, this will receive the first impact during a roof collapse, followed by the table. For this reason, the old A-frame chair design has been reviewed for improvement to increase its strength.

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[6] Photo by author after the earthquake in Balakot, Kashmir.