APPLICATION OF STEEL IN HOUSING CONSTRUCTION – WALL SYSTEM

INDUSTRIAL DESIGN PROJECT II

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2015

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I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea / data / fact / source in my submission. I understand that any violation of the above will be cause for disciplinary action by the institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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Approval Sheet

This Industrial Design Project entitled **"Application of Steel in Housing - Wall",** by **Tushar Wankar**, 136130008, is approved in partial fulfilment of the requirements for Master of Design Degree in Industrial Design.

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Chair Person :

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Date :

Place :

Acknowledgement

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Abstract

India is one of the largest producer of Steel in the world. Even though India has the potential, Steel intensive construction has been quite low and Concrete based construction has been on top mainly due to the lack of awareness of the advantages of steel intensive construction and social mind set about concrete construction.

The project aims at the exploration of the innovative application of steel and finding the scope of use of steel in the construction of the housing. The challenge of developing design and technology that can be deployed easily by the semiskilled/ local labour with minimal tools and power are addressed here. So that it will result in the reduction in construction time, mass producible components, enhance people sense of dignity, identity and belonging.

The Target area focused within the house is internal walls, which aims to improve safety, quality of life and comfort over the long term with sustainable and adaptable solution to local norms without loosing the visual appeal of a traditional brick wall.

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1. Introduction

The housing need in India is increasing at an alarming rate demanding for large number of houses in a very short period of time, which ultimately demands for the technological revolution like prefabricated, modular or quick deployable housing components.

The Project deals with the construction of housing wall panel using corrugated sheets of steel, joined in a cross-cross manner. The concept is based on the modularity, in which corrugated sheet of different sizes are the modules, joined in a criss-cross manner to create wall of a required size along with spaces for windows and doors.

It is tried to solve the problems associated with both primary and secondary users including assembly of wall panel, joining details, issues of electric and plumbing fittings, wall mountings, and also the handling and transportation of sheets etc.

India is among the largest producers of the steel in the world, though it has the potential the steel intensive construction is very less due to lack of awareness about the advantages of steel. Spreading awareness about the advantages of steel over traditional concrete construction is considered here.

1.2 Motivation of the Project

As per the report of the Technical Group on Urban Housing shortage in India (2012-17), India needs 18.8 million housing units in the cities alone, out of which more than 95% are in the Economical Weaker Section/Low Income Group categories.

The task of providing affordable housing in India is bringing new challenges to getting projects ready in record time.
The scope of the challenge for quality housing in India, can meet with Technological involvements, innovative building materials, fast construction methodologies, quality products and industrialized housing can fulfill the needs

1.3 Initial Project Brief

- To develop design and technology for the house wall panels
- can be erected by local labour with minimal tools, power and skills
- Enhance people sense of dignity, identity and belonging.
- To improve safety, quality of life and comfort over the long term
- Provide sustainable long term solutions that are adaptable to local norms
- That are cost effective and acceptable to local populations
- To optimise the construction time of the house
- To reduce the cost of manufacturing house
- Mass producible components
- To fulfil the expectations of flat surfaces painting and mountings of various objects like shelf, photos, TV sets on the wall

1.4 Scope of the Project

The huge number of the required houses that are to be built in the short time, direct the solution providers to take the fast producible or prefabricated building architecture and implementing it in Indian context.

The issues such as Indian culture, value systems, beliefs, socioeconomic aspirations, lifestyle and personal experience of living in a house needs to be addressed

Many of the solutions provided by the prefabricated housing solutions lack the emotional value attached to the housing needs of a typical Indian family and society. The key to success of the prefab housing solutions to Indian housing needs is to address these emotional values of the design.

In this project there is a good possibility that India might see the day the housing issues have been solved.

1.5 Why Steel?

India is one of the largest producer of Steel in the world. In the year 2013, India has produced 81.2 Million Tonnes of steel to achieve the status of Fourth largest producer of steel in the world, only after China, Japan and the USA.

The consumption of finished steel in India, which is the key indicator of the growth of the economy has been quite low. In the year 2013, the consumption was only 74 million tonnes which is approximately 1/8 of the amount of steel consumed by China.

The increase in the per capita consumption of steel in the countries like China, Japan, USA, Australia is mainly due to the popularity of steel intensive construction in these countries.

In India Even though it has the potential, Steel intensive construction has been quite low and Concrete based construction has been on top

This is mainly due to the lack of awareness of the advantages of steel intensive construction and social conditioning about concrete construction.

Concrete is not environment friendly the value after usage of concrete is obsolete where as the steel has the resale value as it its 100 % recyclable

2. Design Process

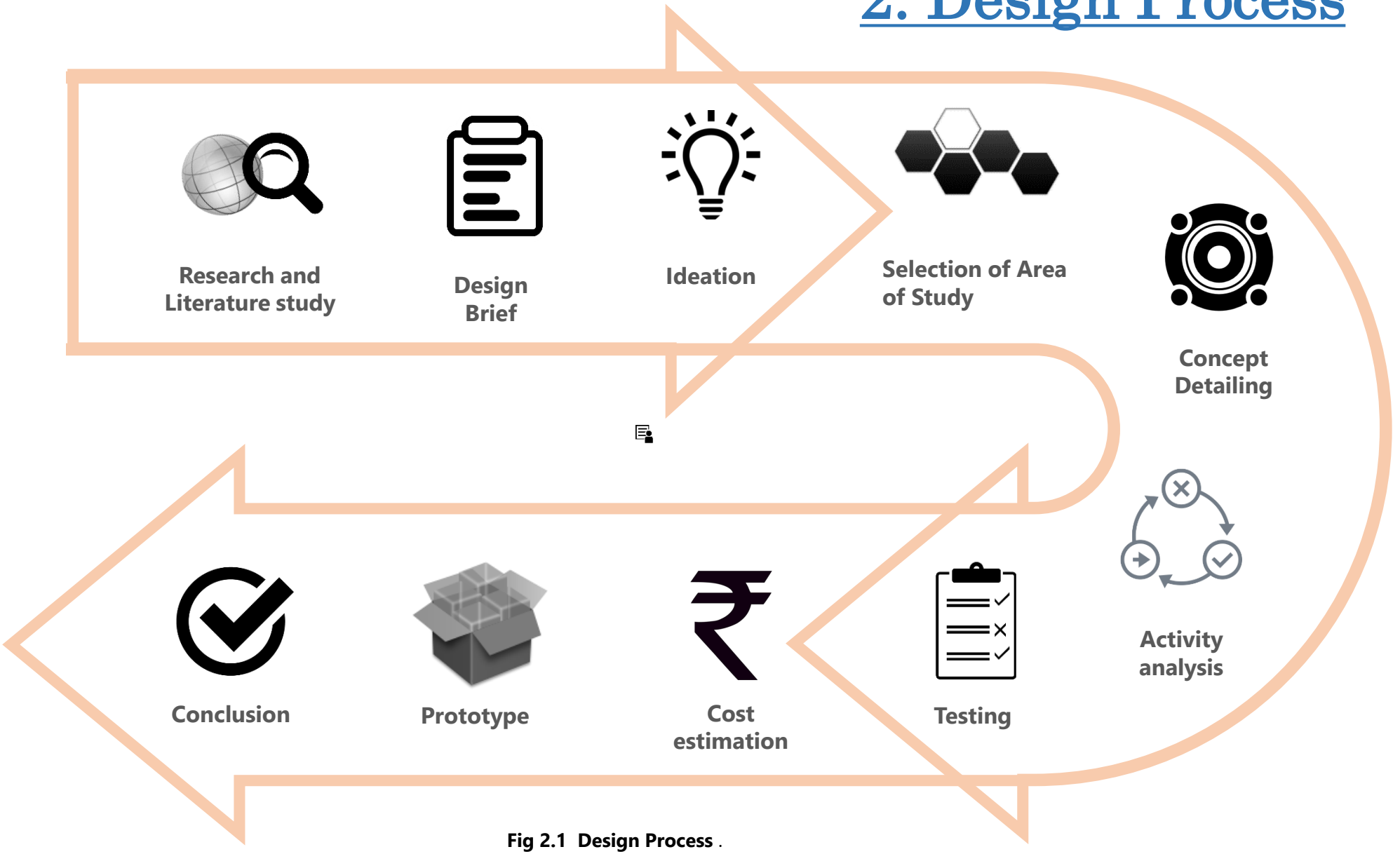


Fig 2.1 Design Process .
Source: Author

3. Review of Literature

The design process starts with the setting up the objective for of the project i.e. use of steel in the housing construction, also after discussion with the guide and based on personal interest the area chosen within the housing is the "wall system"

Research study

After finalising the area the work, the research study is started on gathering information about the needs, problems and scenario of the housing in India. Important aspect are jotted down and initial design brief is constructed.

The research study involved Critical analysis of each and every aspects is studies based on following

- Housing in India, types, scenario and trends.
- Types of walls and their construction methods.
- Detailing with the wall including fixtures, fittings such as electric and plumbing
- Understanding the Steel, its properties and possibilities.
- Working with steel i.e. manufacturing processes,
- Prefabricated panels and types
- Material study for aesthetics

3.1 Housing In India

Figure 3.1 Building construction in metro cities
Source: http://www.marinersociety.com/imagetemp1/proj111808125032pic1.jpeg

Figure 3.2 Types of houses in developing city
Source: http://www.worldpropertyjournal.com/news-assets/india-nki.jpg

Housing in India varies greatly and reflects the mix of socio-economic mix of its vast population. The type of construction is affected by many factors such as population, number of family members, ground space available, land cost etc.

Fig. 3.1 shows the type of houses in megacities of India for middle-class people. These are the multi-storey buildings constructed because of high land cost.

In fig. 3.2 the type of houses seen are small ground + 1 floor in general. This is the scenario particularly where the land cost is not so high.

In fig 3.3 these are the common type house in the villages, corrugated or Mangalore tiles roof, minimal use of concrete, wood columns are the some of the features

Figure 3.3 Common type of house in Indian villages
Source: http://toolbox4change.blogspot.in/

Figure 3.4. Building construction using concrete and red clay brick
Source: http://www.indiamart.com/arvindconstructions/building-construction.html

Figure 3.5. ground +1 floor house construction
Source;
http://upload.wikimedia.org/wikipedia/commons/3/3b/Ishtika_House_Construction_-_Saradas.jpg

3.1.1 Construction material

The majority of houses in India are build using traditional masonry construction method. there is a deep historical and psychological attachments to masonry construction that has contributed to its continuation as the main building method in the India. Read sand clay brick is found almost everywhere in India and most widely use as a building material. In villages the locally available material like cow dunk, clay, dry grass are also used for the construction. fig 3.4, 3.5 and 3.6 show the brick wall construction method used for mostly all type of housing construction

Figure 3.6 . House construction for ground floor
Source: http://www.thehindu.com/todays-paper/tp-national/tp-tamilnadu/tardy-progress-in-housing-project-work/article156632.ece

3.1.2 Wall

In terms of their function, all walls are either load bearing or non load bearing walls. A load bearing wall is part of the structure of the building - it holds the building up. A non-load bearing wall is only a partition that divides the various rooms of a building.

a non load bearing wall can be demolish or moved but the loadbearing cannot. Multi-storey buildings are constructed with structural frames and non-load bearing walls. Most residential buildings in the US, and nearly all wood framed buildings are constructed with load bearing walls

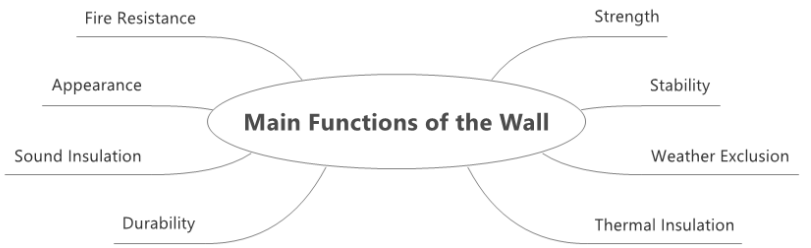


Figure 3.7 Important functions of wall

Exterior wall

an exterior wall assembly contains materials that keep the rain and wind out, thermally insulate the inhabitants from exterior temperatures, structurally support the building and the associated enclosure system, and provide desired interior and exterior finishes. In addition, windows, doors, vents, and other apertures connect to the interior and exterior of the building (ref fig. 3.9)

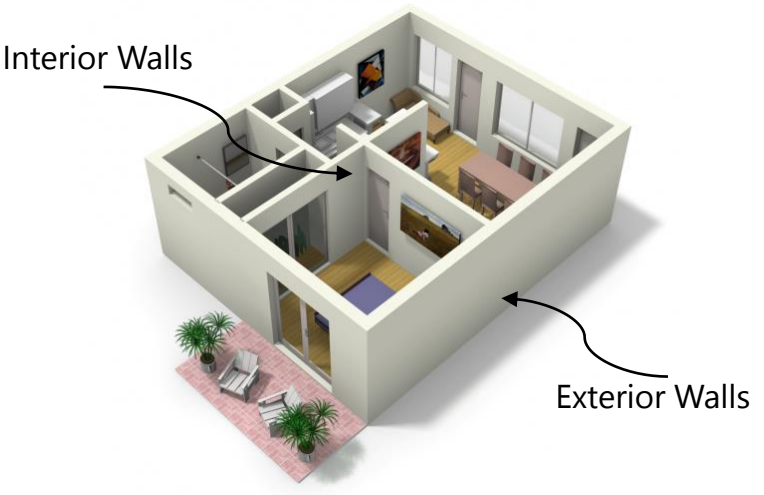


Figure 3.8 Exterior and interior walls of a house
Source: http://tinyhousetalk.com/live-work-small-apartment/

Interior wall

Within interior wall construction there is a wide range of materials and construction techniques used to build walls.
an interior vertical surface can be categorized as:
wall: a general term for one of the sides of a room or a building, connecting the floor and the ceiling, or roof.
partition: an interior non-load bearing wall
screen or panel: a prefabricated building component that is typically broad and thin

Figure 3.9 Concrete brick wall construction
Source: http://www.brickwell.co.in/

Figure 3.10 Fly ash brick wall construction
Source: http://www.hydraformasia.com/wp-content/gallery/ngo-social-sector/rural-house.jpg

Masonry Walls:

these are walls made of brick or cement blocks held together with cement mortar and are often plastered with cement plaster on both surfaces. Masonry walls are heavy, and require lots of skilled labour. Their weight is also a problem in high-rise buildings.

Various Types of Bricks

As the new technologies and material are emerging the newer types of bricks are used in the housing construction

They are characterized on the basis of cost, strength and place in house where it is being used, for example common clay bricks are low quality and low compressive strength but are very useful for internal wall which will not be seen

Concrete engineering bricks (fig. 3.9) are high compressive strength and low water absorption extensively used for exterior of the wall. Fig is shows the building made from concrete bricks.

Latest trend of using ash clay bricks has been emerged in the market nowadays. These are made from the raw material called as fly ash which the waste obtained from the thermal plants. Fig shows the houses made using fly ash bricks. (fig. 3.10)

3.1.3 Generalised wall construction process

Approximate Number of days required

--	3days	1 day	4 days	3 days	1 day
Primary Preparation	Brick Wall Construction	Making Cavities for for Piping	Plastering	Putty And Painting	Electric and plumbing fittings

Mortar preparation and base laying

Brick laying process And edges pointing

Making cavities for pipe conduit

Plaster

Putty and painting

Electric and plumbing fittings

Fig. Brick wall construction method for10 ft. x 10 ft. wall
Image source: http://www.buzzle.com/articles/how-to-build-a-brick-wall.html
http://www.lakshmiandco.in/images/wall-groove-in-action.jpg
http://www.howtospecialist.com/wp-content/uploads/2012/02/How-to-plaster-a-brick-wall-2.jpg

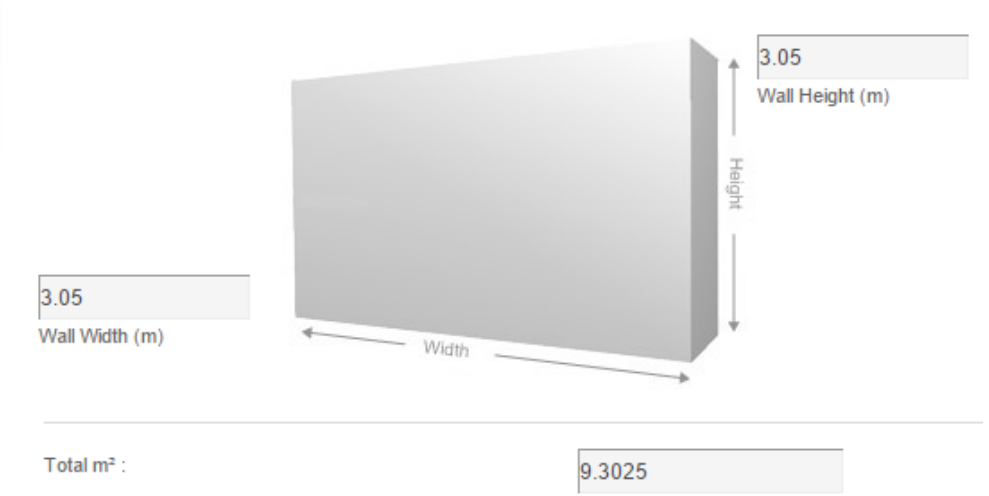


Image 3.12 Size of the wall 10 X 10 Ft
Source: http://www.cashbuild.co.za/Bricks_blocks_and_mortar.php

3.1.4 Brick wall cost calculation [1] [2] [3]

Hypothesis

1. Transportation cost is not included
2. The size of the wall is taken as 10 X 10 feet (3.05m X 3.05m)
3. The cost materials bricks, cement, river sand etc. Varies from place to place in India.
4. These cost estimates are made on the basis of source available on web. And the material cost is taken from the local venders around Powai, Mumbai area as well as distributors available on web.
5. The 5% wastage is assumed in the mortar for brick wall construction.
6. The 10% wastage is assumed in the plaster mortar construction.
7. The size of the brick is taken is the average size of bricks available in India
8. Labour cost for plaster is based on the per sq. Meter of surface area. It is taken as s50 Rs per sq. Meter.
9. Plumbing and electric fittings cost is not assumed here only its fitting cost is assumed

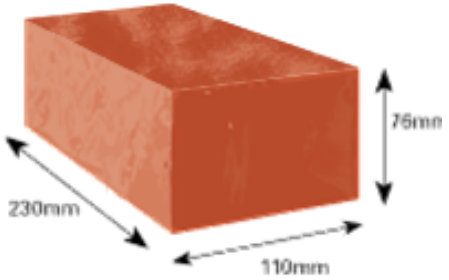


Figure 3.13 Brick dimensions

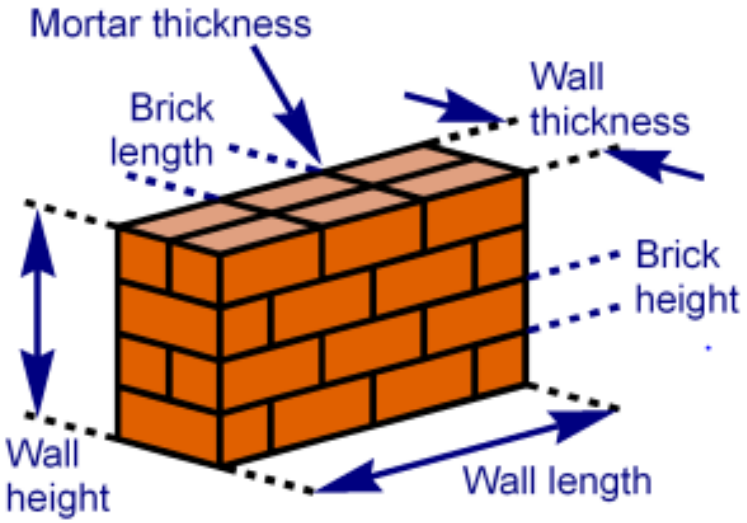


Figure 3.14 Brick nomenclature
Source: http://sepindia.org/wp-content/uploads/2011/08/RTB3.jpg

Number of bricks required-
Single brick wall
Wall size = 10 feet ×10 feet wall
Standard brick size = 230×110×76 (8.5*4*2.5)
Mortar thickness = 10mm
Total no of bricks required = **496 no's**
Cement bags required: 75 kg (approx. 1.5 bags)
Sand – 290kg

Material cost

Wall		
Bricks - 496 *5 Rs per brick	=	**2480.00**
Cement- (82kg) 2 *300/bag	=	**600.00**
Sand – 290 kg *	=	**300.00**
Plaster From both sides		
Cement – (75kg) 1.5*300*2	=	**900.00**
Sand 0.56m3 -	=	**600.00**
Labour cost		
Wall	=	**1000.00**
Plaster	=	**1000.00**
Electric fitting	=	**1500.00**
Total (single lay brick)	=	**8380.00 approx.**
for double brick wall	=	**16800.00 approx.**

3.1.5 wall mountings

Every house owner likes to decorate his house. Not only decorative items but also daily basic objects needs to be hang on the wall needs supports. it includes decorative art-piece, lamp shed, paintings Tele-vison set, shelf, etc. (refer fig. no. 3.15- 3.18)

The most important thing for carrying out activities is to fix a screw or hooks in the wall which will take the load and it has to be firmly fit into the wall. It needs to satisfy the safety factors and load-bearing capacity also.

While designing the wall these things need to be taken care for easy installation of these items.

Figure 3.15. lamp

Figure 3.16. Shelf

Fig 3.17. LCD TV

Fig 3.18. Photo Frames

Source: http://www.firstfurniture.co.uk/product_images/n/traditional%20wall%20lights__72362.jpg
http://www.thedormyhouse.com/images/shop/peg_shelf.jpg
http://www.imagesfeed.com/images/ebay/BCAW-0507R.jpg
http://fwds.in/wp-content/uploads/2012/09/Cool-Ideas-to-Display-Photos-on-Wall-10.jpg

Key insights

Building brick wall with no prior experience in masonry is a challenging task, some amount of skill is required for getting it done in a correct way.

To run electrical, or any other wires or pipes in a brick wall, a long groove is required to be cut in the wall.

The amount of time required for the construction of a complete wall system is high as the processes are dependent on previous. Also the concrete takes time for drying hence it takes time for complete wall completion

Masonry walls cannot be constructed to an unlimited height it remains stable only to a height of 10-15 ft. (3 - 4m). A support structure is required to support the wall.

One problem with masonry walls is that they rely mainly on their weight to keep them in place; each block or brick is only loosely connected to the next via a thin layer of mortar. This is why they do not perform well in earthquakes

For the replacement of the concrete with steel 3 essential factors need to be addressed

Designs of the wall

Methods

Equipment

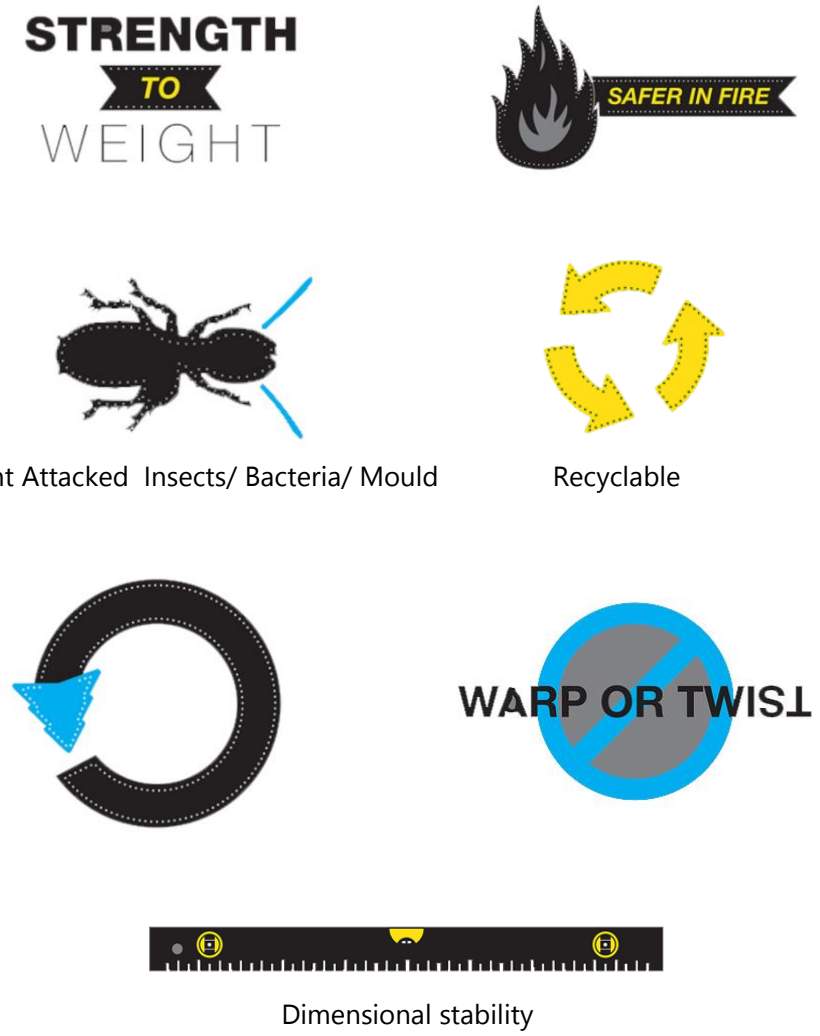


Fig 3.19. advantages of steel
Source: http://sa.rivergumhomes.com.au/timber-steel

3.2 Steel in Construction

3.2.1 Advantages of Steel

- It is strong, light, tough and durable
- It will not rot, burn, distort or be attacked by insects/bacteria/mould
- It can be formed, worked, shaped & joined into almost any structure
- It is resistant to most environments with appropriate treatments
- It allows buildings to be redeveloped & altered at low cost to meet changing needs
- It can be readily recycled & reused at the end of its life.
- It can readily transported either as a component, panel or module.
- It lends itself to a variety of construction techniques.
- It offers unique material advantages in strength & weight.
- It can be designed for a wide range of conditions Earthquakes, Typhoons. Hurricanes, floods etc.
- It can be adapted/extended by families for future needs.
- Can be erected with minimal tools and access to electricity

3.2.2 Important considerations for housing

- **Fire Safety**

Fire safety factors such as: effective means of escape in fire, prevention of fire spread, structural stability, and the provision of effective fire fighting measures are important. Requirements for structural stability and compart mentation are usually expressed as the 'fire resistance' of the structural elements. Generally, for walls and floors, the measures introduced to achieve satisfactory acoustic insulation also achieve at least 60 minutes fire resistance.

- **Thermal Performance**

One of the most effective ways of reducing primary energy consumption is by improved thermal performance of the building envelope, such as by reducing thermal transmission and improving air tightness. Thermal insulation of the. This can be achieved by using insulation placed externally to the light steel walls and roof so that the risk of cold bridging and condensation is minimised.

- **Loading**

types of loading to be considered in the design of housing are: Self weight (including finishes). Imposed loads (including higher loads in communal areas).Wind actions.

- **Sustainability**

steel is 100% recyclable All steel construction systems can be re-used or recycled at the end of their life.

- **Speed of Construction**

A characteristic of all steel technologies is their speed of construction on site and improved productivity through efficient construction

- **Long-term Use**

The design life of housing and residential buildings is typically 60 years in terms of the primary structure and building envelope. Galvanised steel components are durable and long lasting, as shown by measurements of buildings in different climatic conditions. A design life of over 100 years is predicted for steel components contained within the building envelope.

- **Flexibility**

buildings must be flexible in use and adaptable to future demands, which steel technologies can achieve through use of re-locatable partitions, longer span floors and use of 'open' roof systems.

- **Safety**

The steel wall panels can be made lightweight, it can be used for the protection in natural calamities, earthquake and disaster management

While using steel as a material for the construction of the housing, following factors are has to be consider.

It is divided into 3 categories

Critical

Density

Strength

Dimensional stability

Flexibility

Very important

Fire resistance

Sound insulation

Thermal insulation

Economical

Important

Workability

Sustainability

3.3 Parallel Product Study

It involved the study of existing houses in India and abroad which are made using steel and similar materials.

To understand the technological innovations happening in the field of steel, various products from the areas such as shipbuilding, automobile, aviation are studied

3.3.1 Dichromic Analysis

Case study 1
Temporary multi-storey building
Ramabai nagar, Ghatkopar, Mumbai

The construction is happened under the rehabilitation plan for the slums. In order to avoid migration of thousands of people during construction period they decided to build a temporary shelter in a small area of the land. It is a 16 storey building with 12 rooms on each floor is constructed with steel. Reason for making a multi-storey building is the space limitation The structure is made of a steel 'C' sections (joined by facing each other) Flooring is made of composite material of corrugated sheet and concrete (fig. 3.20 and 3.21)

The entire structure is welded and the other components are fastened with the nut-bots. For flooring and roofing the corrugated sheet is used of approx. 1.5 mm thickness which is proven sufficient to take load.

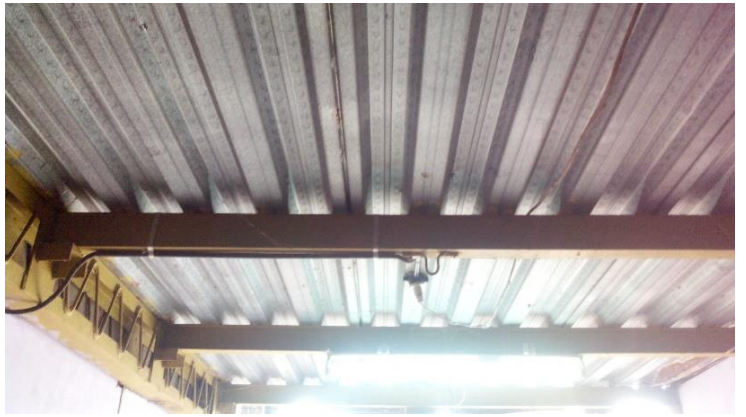


Figure 3.20. slab construction using corrugated sheets

Figure 3.21. columns made using 2 'C' sections joined closed together

Fig3.22. Column made of 2 'C' joining together

Fig3.23. Partition – made by Bison Board

The temporary partition and exterior walls is constructed by using a Bison Board. It is 15 mm thick and weather proof, heatproof and strong used everywhere as a wall partition and facing wall As shown in fig. these are not load bearing. all the detailing that has done keeping in mind the service life of 10 years.

The construction time is less than a 1.5 years which is possible because of the innovative simple design and engineering and selection of appropriate material.

Steel has a lot of potential and application. here the champion properties of steel are identified and designs are made accordingly to suit various requirements of the building construction which resulted into a time saving construction technique. Innovative and creative use of steel is observed here.

Case study 2
Timber housing construction
Huston USA.

Light wood framed construction is one of the most popular types of building methods for homes in the United States and parts of Europe. The wood which is suitable or fit for engineering construction or engineering purpose is called timber

few basic components:

Studs are vertical wooden members within the walls. (fig 3.26)
Joists are the horizontal wooden beams that support the floors.(fig. 3.27)
Rafters are the sloping wooden beams that support the roof.(fig 3.24)
Sheathing are the sheets that are nailed over the studs to connect them securely and form the wall surfaces.
Siding is the exterior cladding that covers the walls from the outside.(fig 3.24)

The external cladding material used is the OSB (Oriented Strand Board). It is the most widely used material for the exterior cladding due to its workability to saw, drill, nail, plane, file, glue, paint, or sand. In addition to that it provides an extra acoustic and thermal control.

Figure 3.24. House made timber frame construction method

Figure 3.25. Interior of the house

Figure 3.26 Timber columns

Figure 3.27 Timber columns

Image source: actual photos take on site of construction Houston U.S.A.
Image credit: Prof. V. P. Bapat

Figure 3.28 Beam and its joining plate

Figure 3.29. Joint for beam support

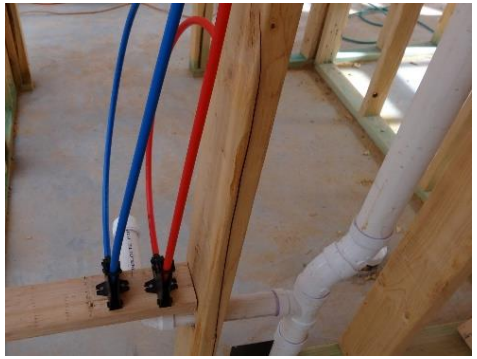


Figure 3.30. Plumbing fitting

Figure 3.31 detail for fixing stud with floor

Image source: actual photos take on site of construction Houston U.S.A.
Image credit: Prof. V. P. Bapat

The walls are load carrying members.

Simple sheet metal plate with innovative design can be used for joining details for every joint (ref fig. 3.28, 3.29, 3.31) It is light, and allows quick construction with no heavy tools or equipment.

Every component can easily be carried by hand - a house essentially becomes a large carpentry job. The main tool is a handheld nail gun.

It is able to adapt itself to any geometric shape, and can be clad with a variety of materials.

Any geometric shape is possible to make

As it is the wood fireproofing is an issue.

Load bearing light steel Framing

Load bearing steel frame wall is made by using C sections with thickness of 1.6 to 2.4 mm. The walls are installed using the floors as a working platform

The structural cross members are also placed in between the studs to distribute the force. Forces are transferred directly through the walls to the floor. Wall studs (vertical C sections) are placed at 300, 400 or 600 mm spacing to align with standard plasterboard widths of 1.2 or 2.4 m. Double layer walls comprising mineral wool or glass wool insulation placed between C sections and two plasterboard layers placed on the outer faces of the wall.

Figure 3.32 Light weight steel frame construction
Source: http://www.structure1.com/html/Light-Gauge-Cold-formed-Steel-Framing.htm

3.3.2 Synchronic Analysis

Caravan wall Panels

A combination of materials are bonded together and vacuum pressed to create a very strong and light sandwich panel.it consist of a following layers (fig. 3.33)

•Aluminum skin provides waterproof, impact resistant outer layer

•Timber matrix provides overall strength to full edge of wall

•Polystyrene matrix offers outstanding sound and thermal insulation and brilliant weight saving

•Plywood inner wall adds further strength

•PVC "wall paper" is tough, easy to clean and finishes off interior beautifully

The frame shown in figure 3.34 is constructed in timber wood and polystyrene matrix is placed from outside and PVC coated plywood is nailed from one side to the frame.

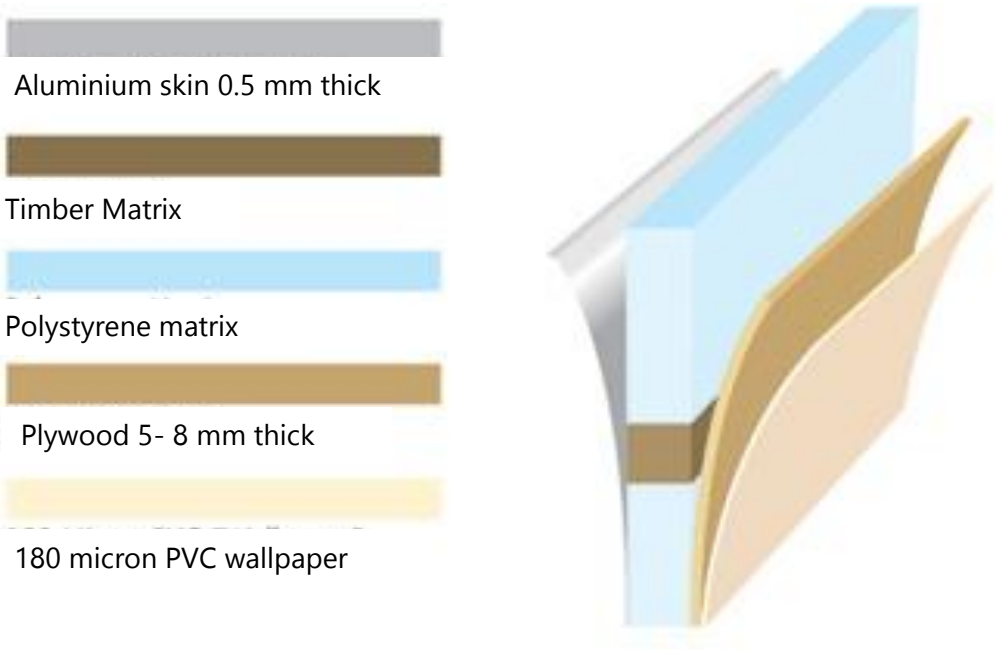


Figure 3.33 Sandwich Panel Used In Caravan Construction
Source: Http://Jurgens.Com.Au/Range/Smart-technology.Aspx

Figure 3.34 Caravan Wall Construction
Source: Http://Jurgens.Com.Au/Range/Smart-technology.Aspx

Case study 3
Stadium Roofing Installation
IIT Bombay SAC

This case study is about the construction activity happening at the Student activity centre inside IIT Bombay. A very interesting detailing for joining the roofing sheet to the structure is observed here. The roofing sheet used here are 1.5 feet wide and 50 to 100 feet long (1) which is bent into a curve and fitted on the structure.

The straight sheets are transported to the site of construction in different sizes to suit the application and in order to avoid the cutting.(1)

The bending machine incorporated in the shipping container is also transported to the site od construction. The machine is capable of bending 100 feet log sheet into a desired curves arch (2). The roofing sheet used are made of aluminium alloy for life of 50 years specified by the manufacturer.

The roofing sheets are snap fitted to the plug (4) which is bolted to the structure frame (6). The design of a sheet is such that the 'snap 1' (3) goes over the plug (4) and "snap 2"(3) of next sheet fits over the 'snap 1' of first sheet and chain continues.

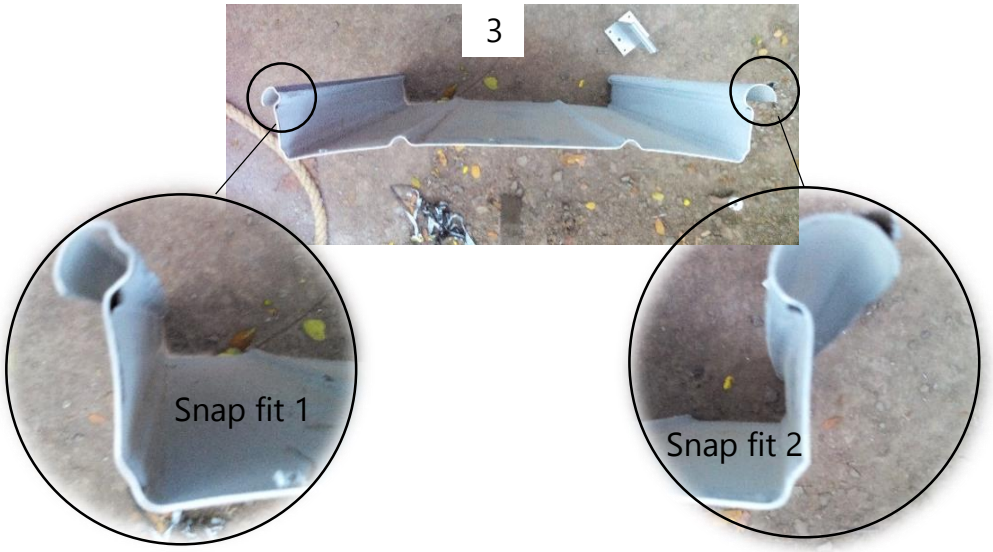
A sealing machine is moved over the joint which presses the sheets together so that sheet wont come out again. Direct contact of sheet with steel structure is avoided by using a spacer (6) and a cork washer is used to avoid contact with the structure.

The complex method of fixing roofing sheet with nut and bolts which required access from both side is to do the activity is avoided here by using a snap plug joint.

Simplicity of joining from one side is very nicely achieved

Roofing Sheet – straight

Roofing Sheet – Bent in a curve (Bending machine transported onsite)



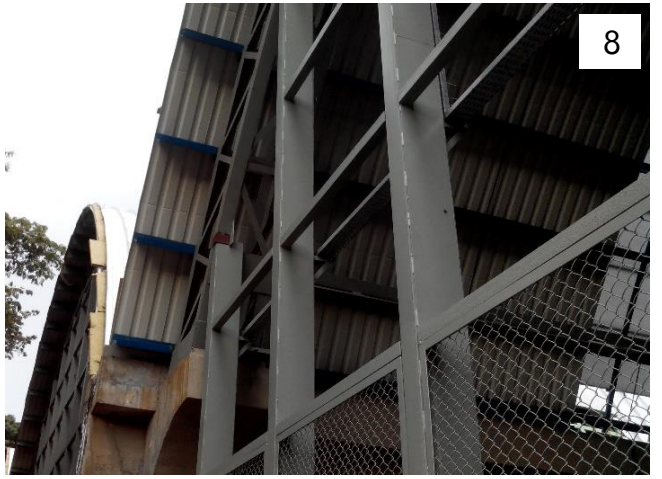
Cross-section of the sheet and end details

Fixture (snap plug)

Cork Washer

Plastic Spacer

Sheet with end 1 fitted over the plug



Corrugated roof fitted on a structure

Figure 3.35 Sheet Metal Roof panel fitting
Source: Author

Shipping container

The shipping container is large steel box used for the shipment handling and storage of goods. The side and end walls and the roof are the components of a standard box container which are capable of bearing the least load. To a certain degree, this naturally also depends on the construction materials used for them.

Fig show the structure of the container which has four columns an are made in square cross section. Corrugated sheet panels are use as a side wall and welded to the frame. It act as a load bearing member.

The total load bearing area covered by the square sections is less than the area covered by the corrugated sheet. Together they can support weight of 8 fully loaded container.

The secret of its capacity is in the Cross section of the columns and arrangement of corrugated sheet.

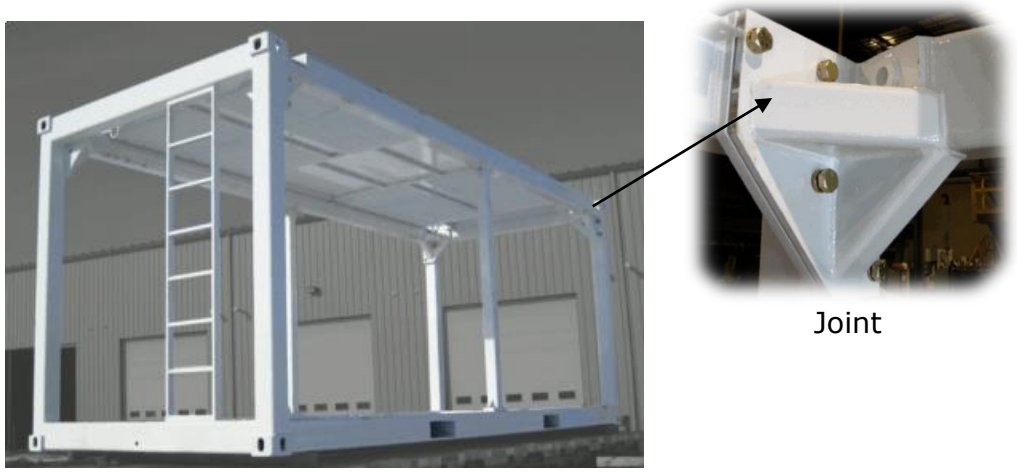


Figure 3.36 Shipping Container Frame
Source: Http://Dahlsonindustries.Com/Projects_csc_dnv_containers.Html

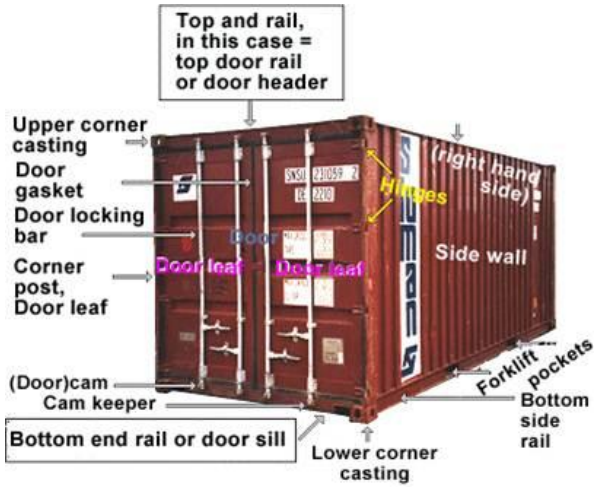


Figure 3.37 Shipping Container
Source : http://imbamnugroho.blogspot.in/

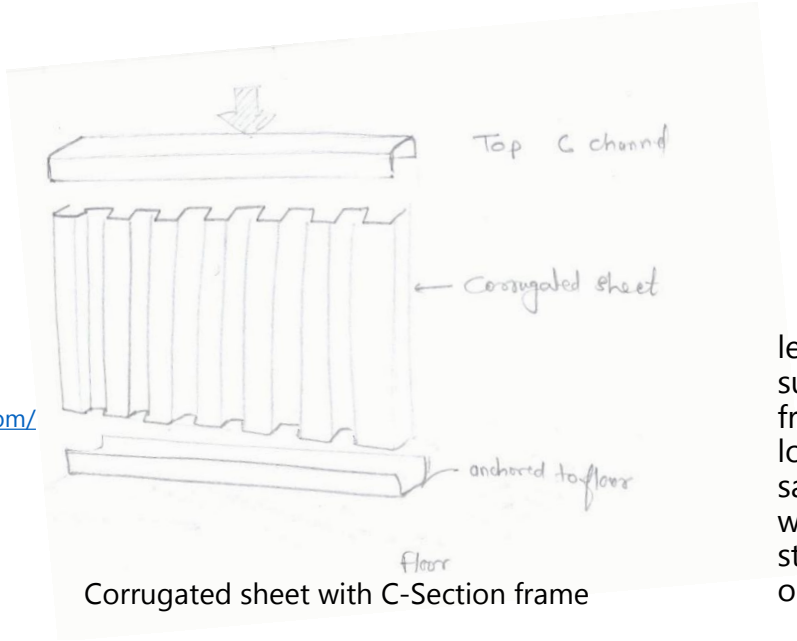
4. Design Brief

- It will be an internal wall of a house
- It will not be a load bearing member
- Wall has the opening for doors and windows
- To make it easy for the semi skilled labour to assemble
- Easily deployable on the site
- To have the same visual appeal as a that of a normal wall
- Enhance people sense of dignity, identity and belonging.
- Provide sustainable long term solutions that are adaptable to local norms
- That are cost effective and acceptable to local populations
- To optimize the construction time
- Transportation consideration
- Aesthetic consideration
- Following users and their issues will be addressed
    - Primary users
        - Residents of the house
    - Secondary users
        - Transporter
        - Plumber
        - Electrician
        - Carpenter
        - Painter

5. Ideation

Inspiration

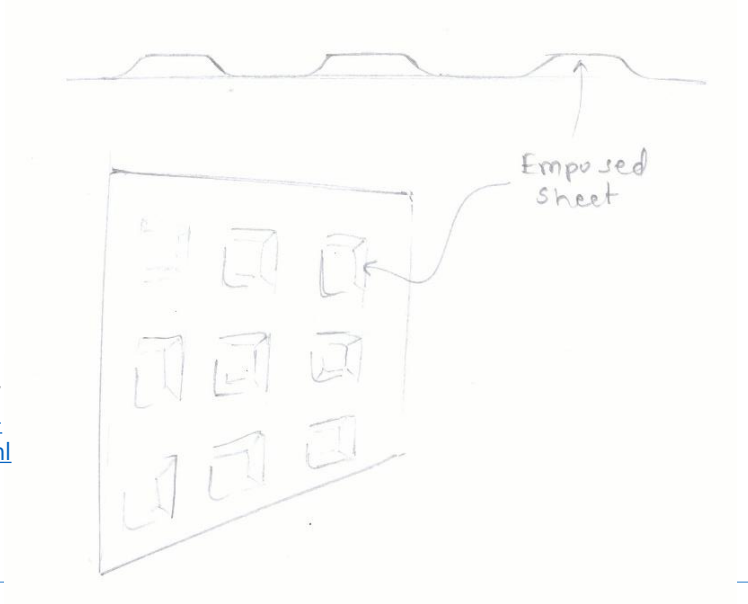
Figure 5.1 Container wall
Source: http://www.chassisking.com/



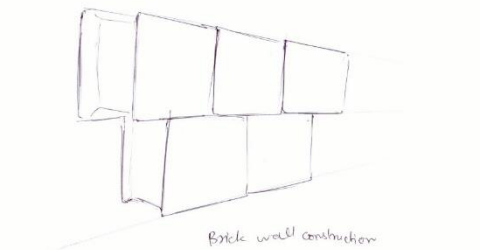
Corrugated sheet with C-Section frame

The corrugation in a metal sheet gives stiffness along its length, this property of corrugation is widely used in industry such as cargo container construction. The containers made from corrugated sheet structure capable of taking 10 times load of fully loaded container (ref fig 5.1). In first idea the same corrugated sheet structure is used to construct a wall with vertical corrugations so that it can provide vertical stiffness. Horizontal strength can be provided with the groove or 'C' sections.

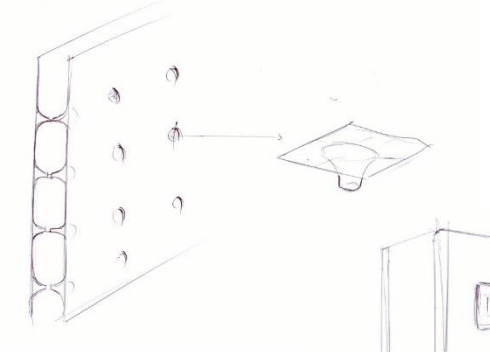
Figure 5.2 Wooden Door
Source: http://www.sydstar-india.com/wooden_door.html



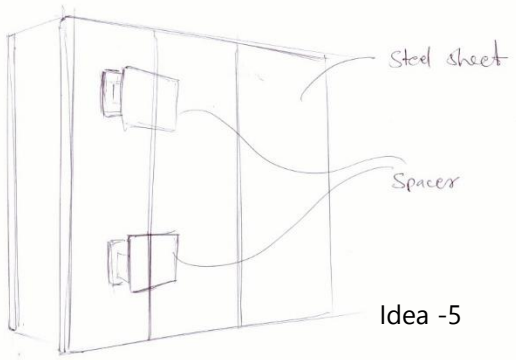
in order to get bidirectional stiffness in a metal sheet, sheet can be embossed with certain height without cracks to give stiffness. The basic principle here is the bends in a sheet creates stiffness which is helpful for the wall construction.



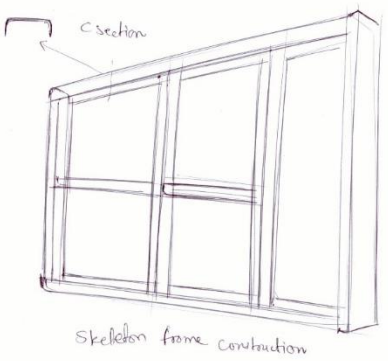
Idea -3



Idea -4



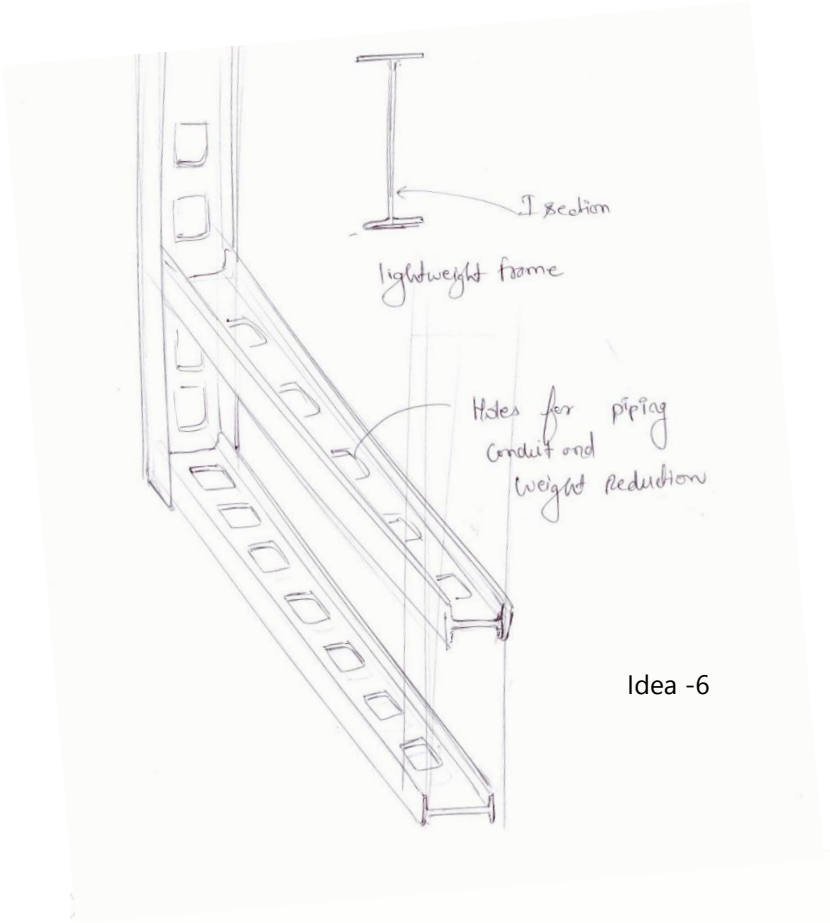
Idea -5



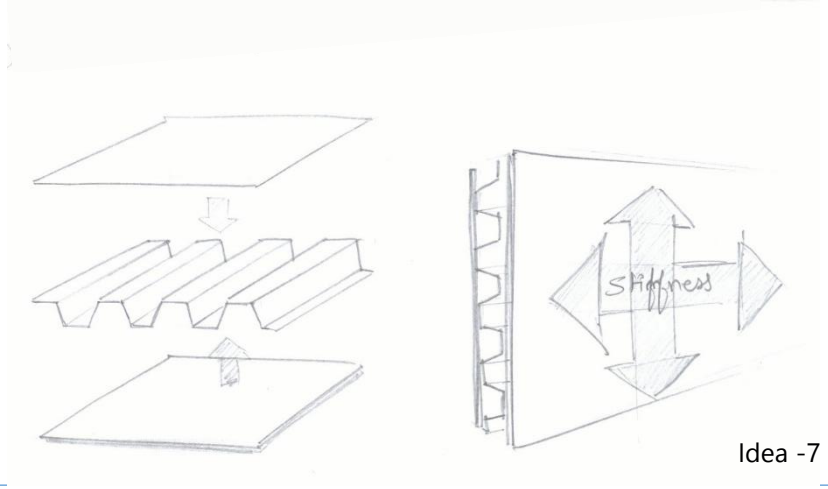
Idea- 3 consist of a modular block made from a single sheet of Metal folded to form a square block with built in interlocking space. These blocks approximately of 1ft x 1ft in size can be interlocked by sliding one over another.

Idea -4 consist of a protruded out points from the sheet of metal tat will be joined by nut and bolts. The reason of providing space between two sheets is provide passage for plumbing and electric fittings and also to provide space for air passage. The protrusions will also provides the strength and stiffness and prevents from wrapping and twisting.

Idea 5 consist of a pre casted metal spacers that also act as joiner of a two metal sheet. It is in the form of a square shape which can be used vertical or horizontal with the grooves helps to hold two sheets together having C-section.



Idea -6

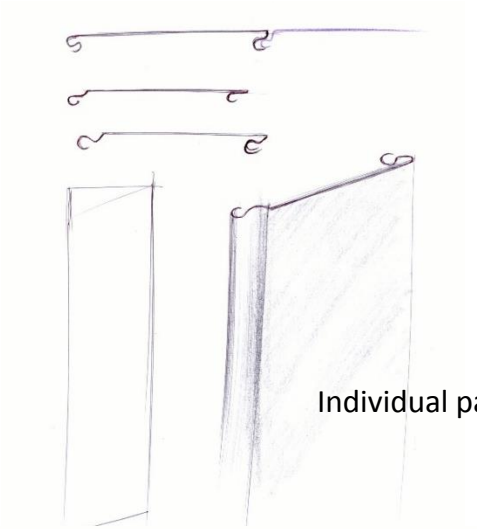


Idea -7

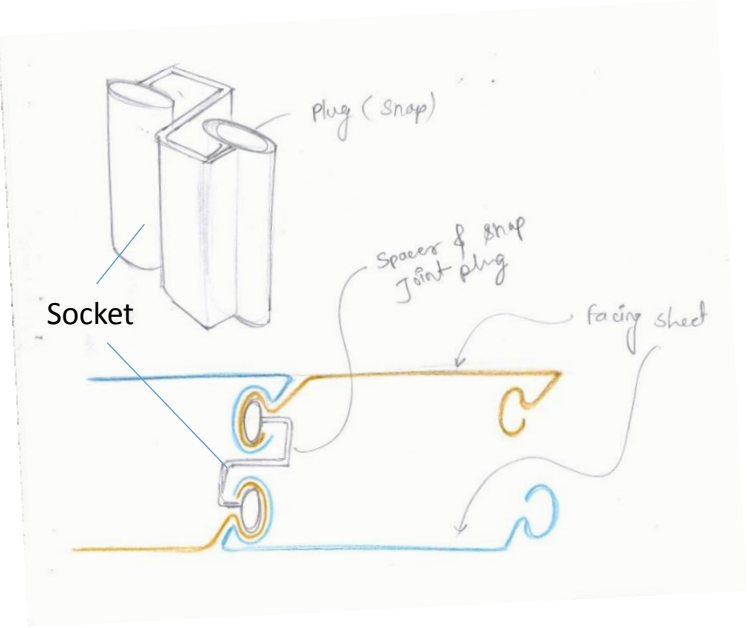
In idea- 7, I sections made from steel with holes in between two vertical members are provided for weight reduction. The sections can act as a structural member for cladding. These sections will be joined by rivets or can be welded on construction site.

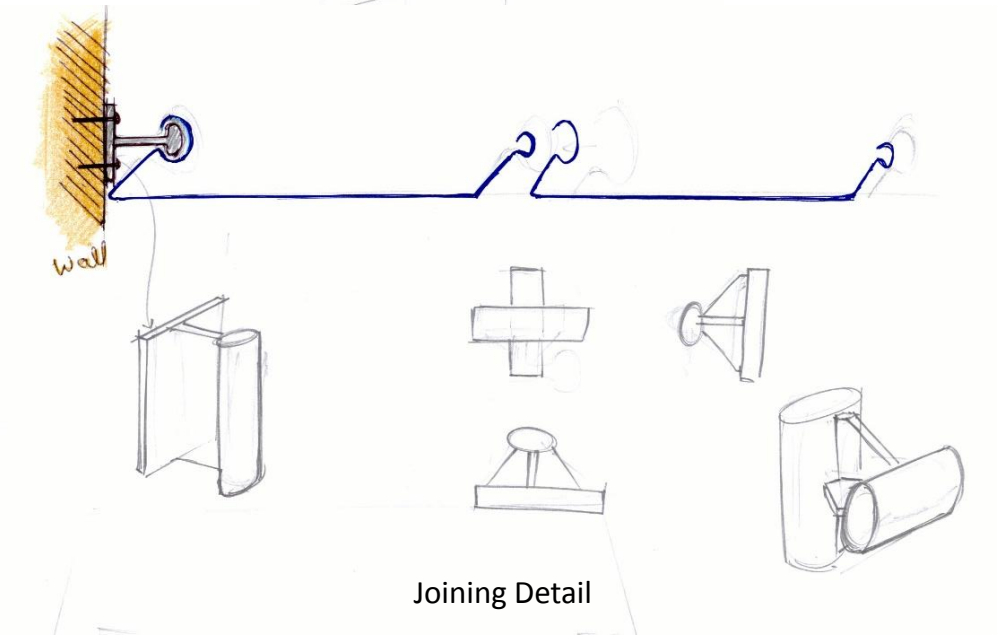
In idea-8, a corrugated sheet is sandwiched between two flat metal sheets. Sandwiching makes panel stiff in both direction and the vertical spaces can be use for plumbing conduits. These panels can be cut into a required size and install along with the concrete columns.

Concept 1

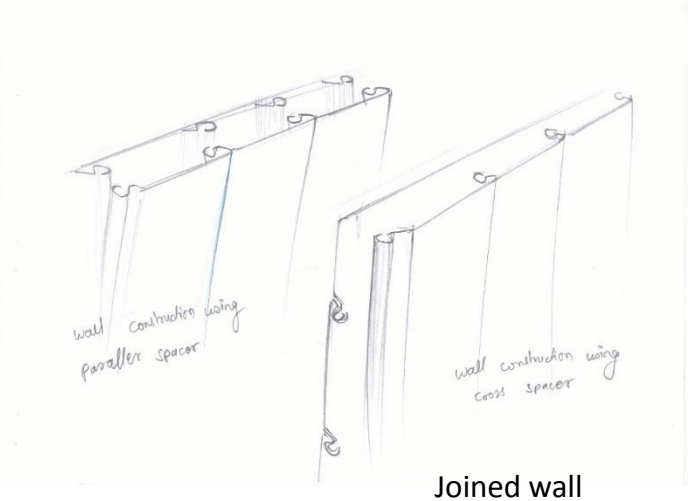


Individual panel





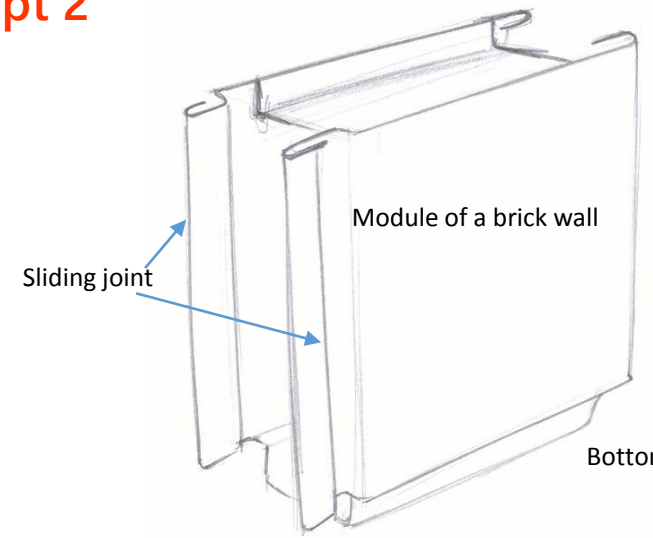
Joining Detail

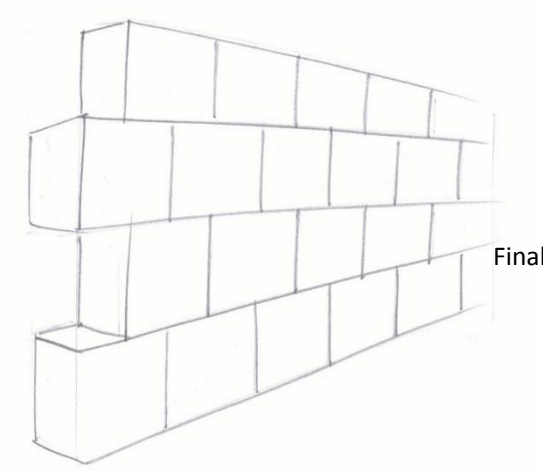


Joined wall

Figure 5.3 Glass Brick Wall
Source: http://www.masonryglass.com/glass-block-walls/

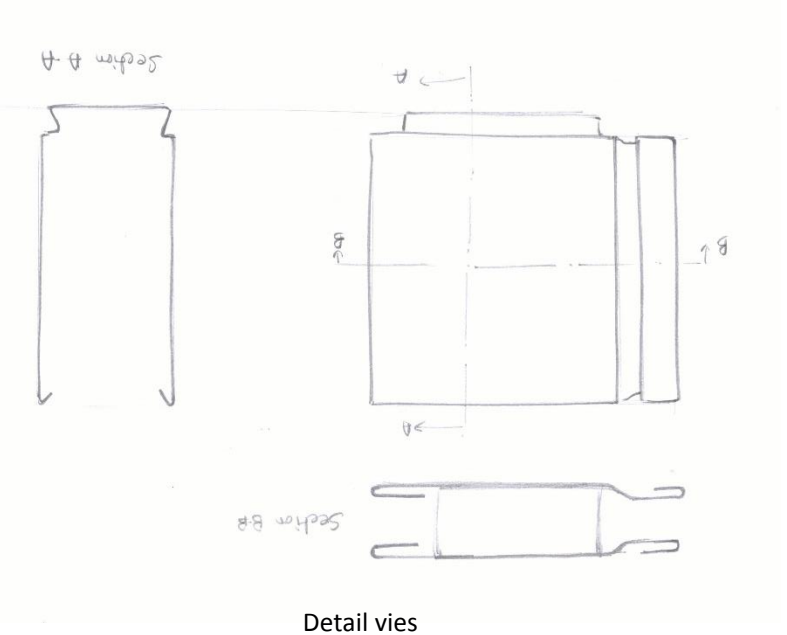
Concept 2





Final brick wall

Using the concept of modularity and traditional overlap joint of sheet metal Each block will fit into another one and will rest in the cavity of the block below. Made in a single sheet bent to form the block of the wall unit



Detail vies

Concept 3

Figure 5.1: Galvanised roof sheets

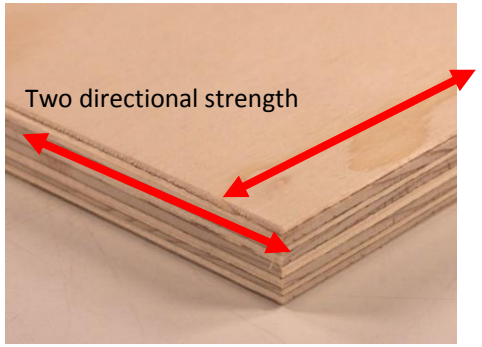
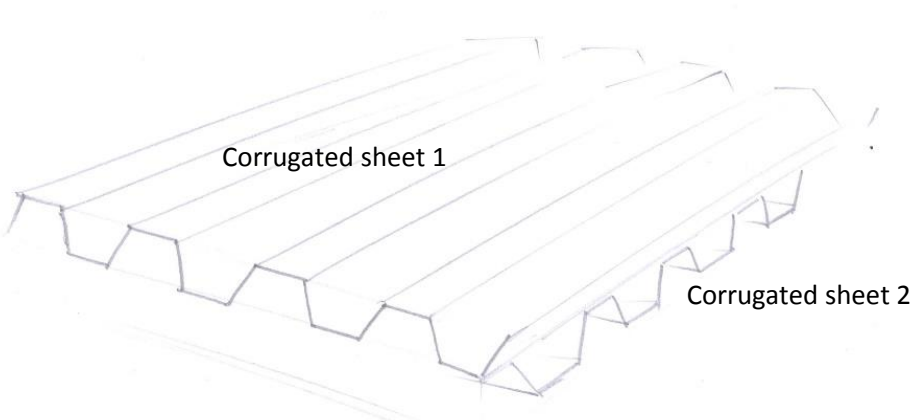


Figure5.2 : Plywood

This concept is taken from the inspiration from the plywood. The plywood has the criss-cross rains which gives the two directional stiffness. The corrugated sheets have one directional stiffness along its length and inn other direction it is flexible to bend

The concept developed by crisscrossing the two corrugates sheet same as in the plywood so that it can be made stiff in 2 directions.



2 directional strength

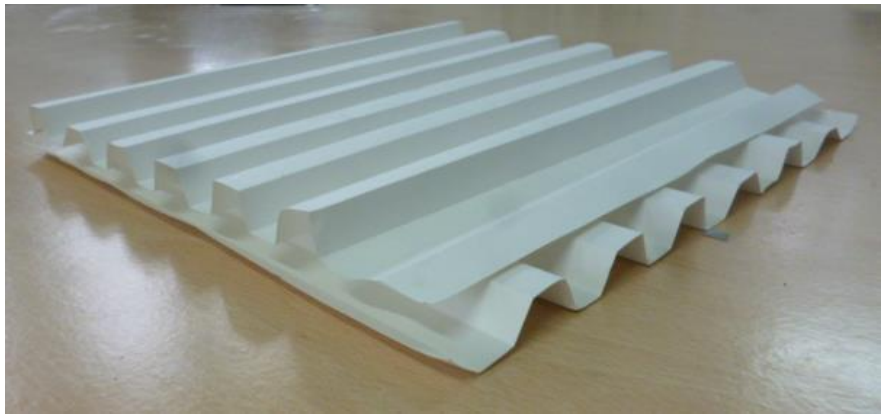
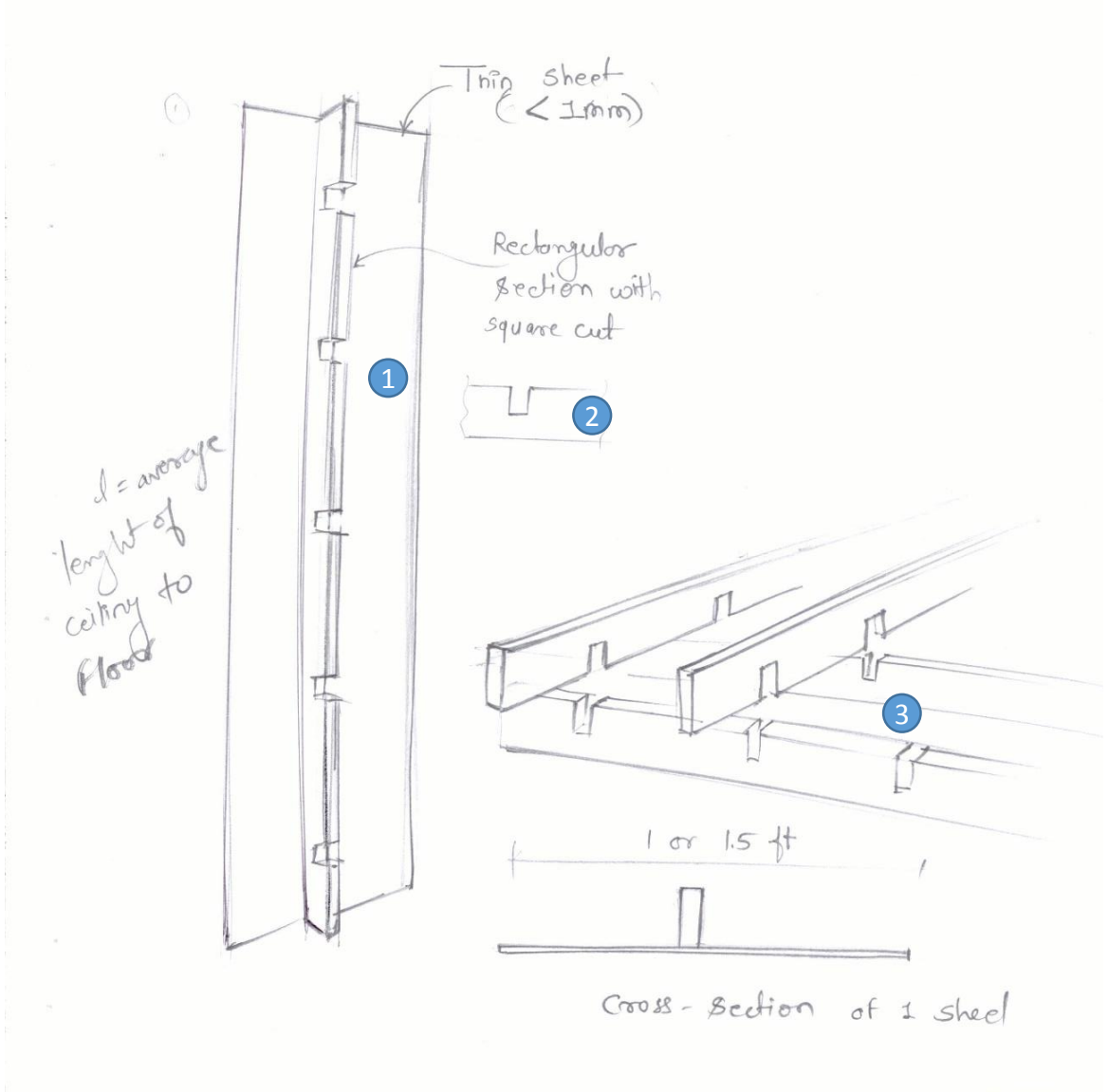
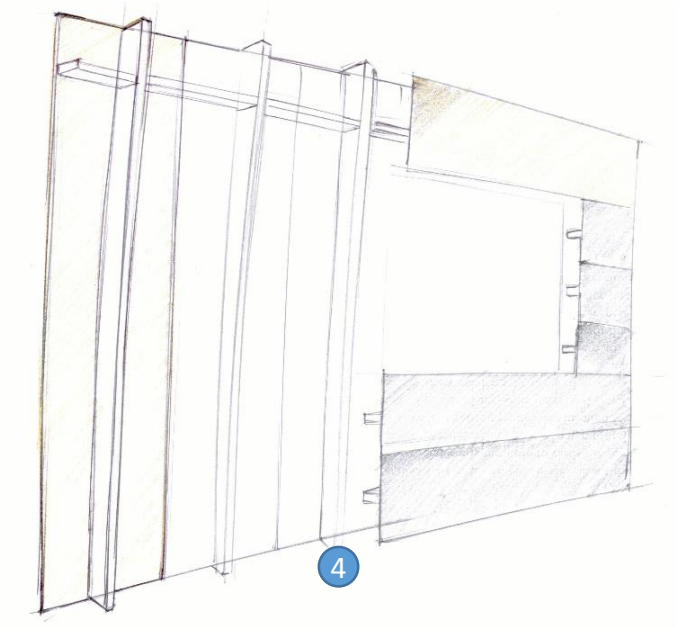


Figure 5.3: Mock-up model of corrugation



Concept 4

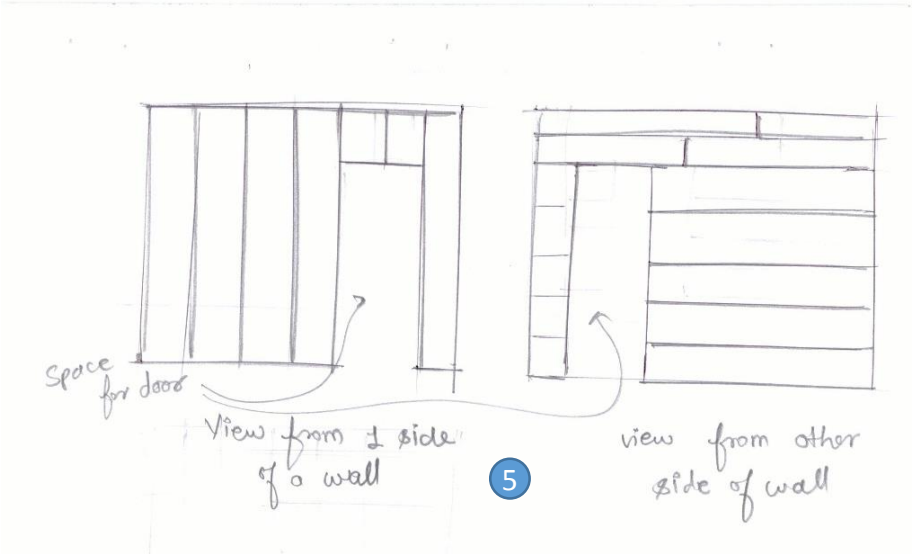
This concept consist of a flat metal sheet of metal approximately 0.5mm thick with a plate welded at the centre forming a T joint (as in 1). The welded section has rectangular slots for fitting (2) duplicate sheet but in cross direction (3). To achieve the modularity the plates can be made available in different sizes as per the requirement. These can be cut also. When assembled it gives a flat face from both sides with strong square grid inside which gives structural strength.



4

(4) Details showing how the space for the window is created by cutting plates as the required dimensions.

(5) shows how wall will look from both side after assembly.



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6. Final Concept

Two directional strength

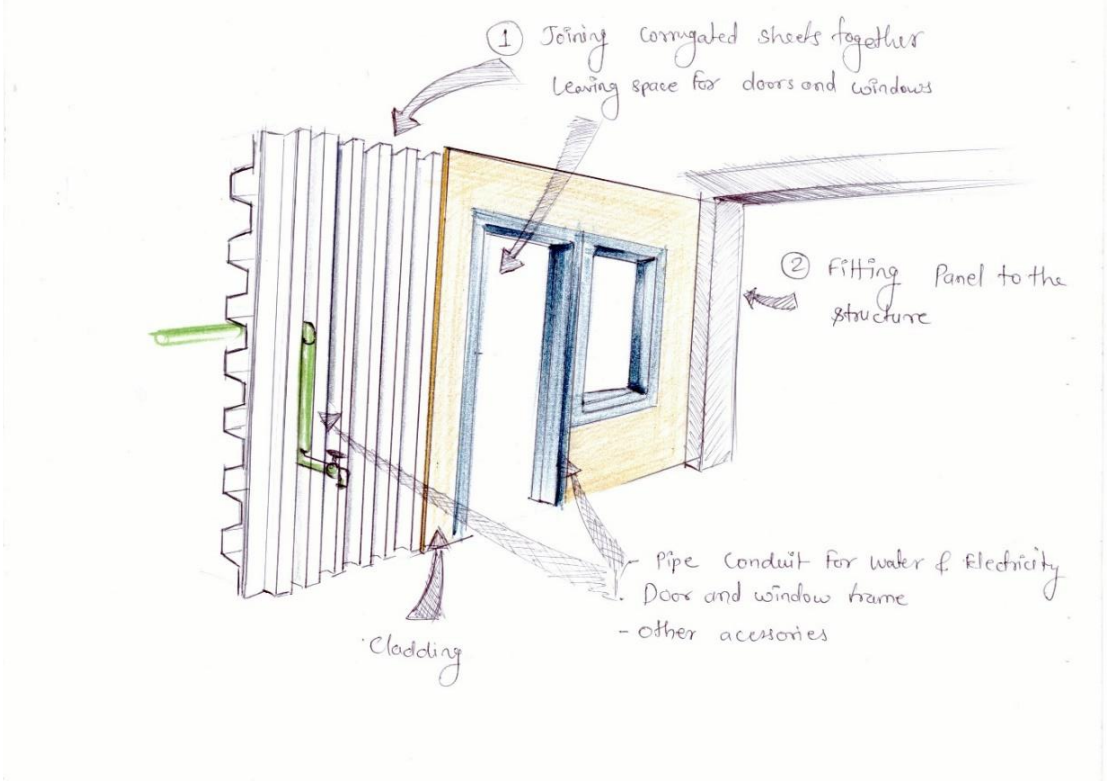


Figure 6.1 Final Concept

the selection of the final concept is made on the basis of simplicity and advantage offers by the construction of wall panel. I The simple wall construction method will be joining of two corrugated sheets together in a criss-cross manner with leaving space for door and windows cut-outs and fixing it to the structure of the house followed by fixing cladding a panels as summarised in figure 6.1

A sample test piece of 2 corrugated sheet joined together is made for exploring the possibilities and understanding the system

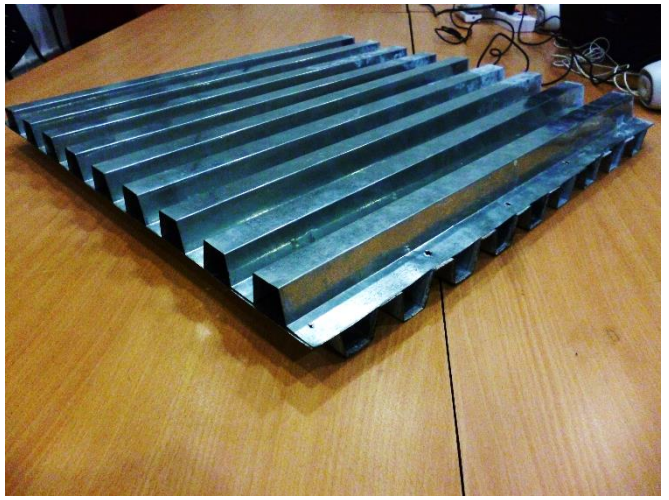


Figure 6.2 Sample Criss-cross Corrugated Sheet Joining

6.1 Advantages of using Criss-cross corrugation

1. Single Corrugated sheet is stiff along its length but in cross direction it is flexible. By joining two sheet sheets together in a criss-cross manner, the two directional stiffness is possible.
    1. As the joints are uniformly distributed over the entire sheet, It will not Wrap or Twist
    2. Stability in all directions
    3. When extreme force is applied the single corrugation can bend but double corrugation in a criss-cross will be more strong (ref Fig 6.4)
2. Sheets will not break into pieces, this property will be helpful in saving life during disaster and natural calamities.

Image 6.3 Disaster Happed During Hudhud Cyclone in India
Source: Http://Tellsnews.Com/Tag/Cyclone/

Image 6.4 Disaster Happed During Hudhud Cyclone in India
Source: http://www.business-standard.com/article/current-affairs/cyclone-hudhud-damage-estimated-at-rs-8-000-cr-114101301099_1.html

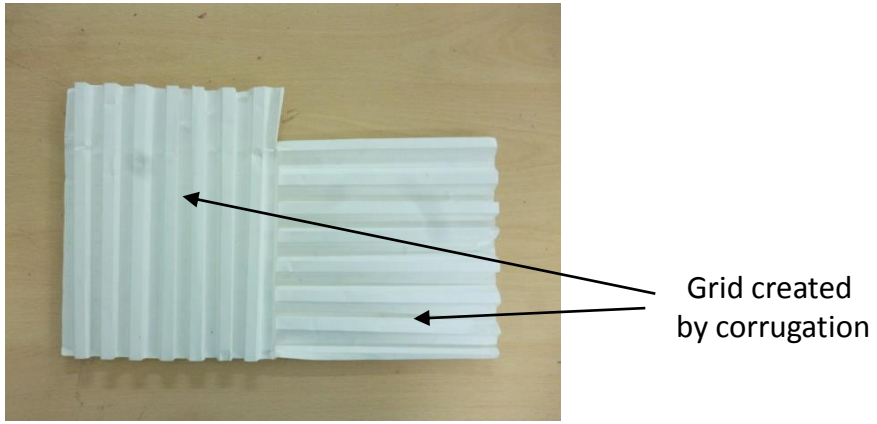
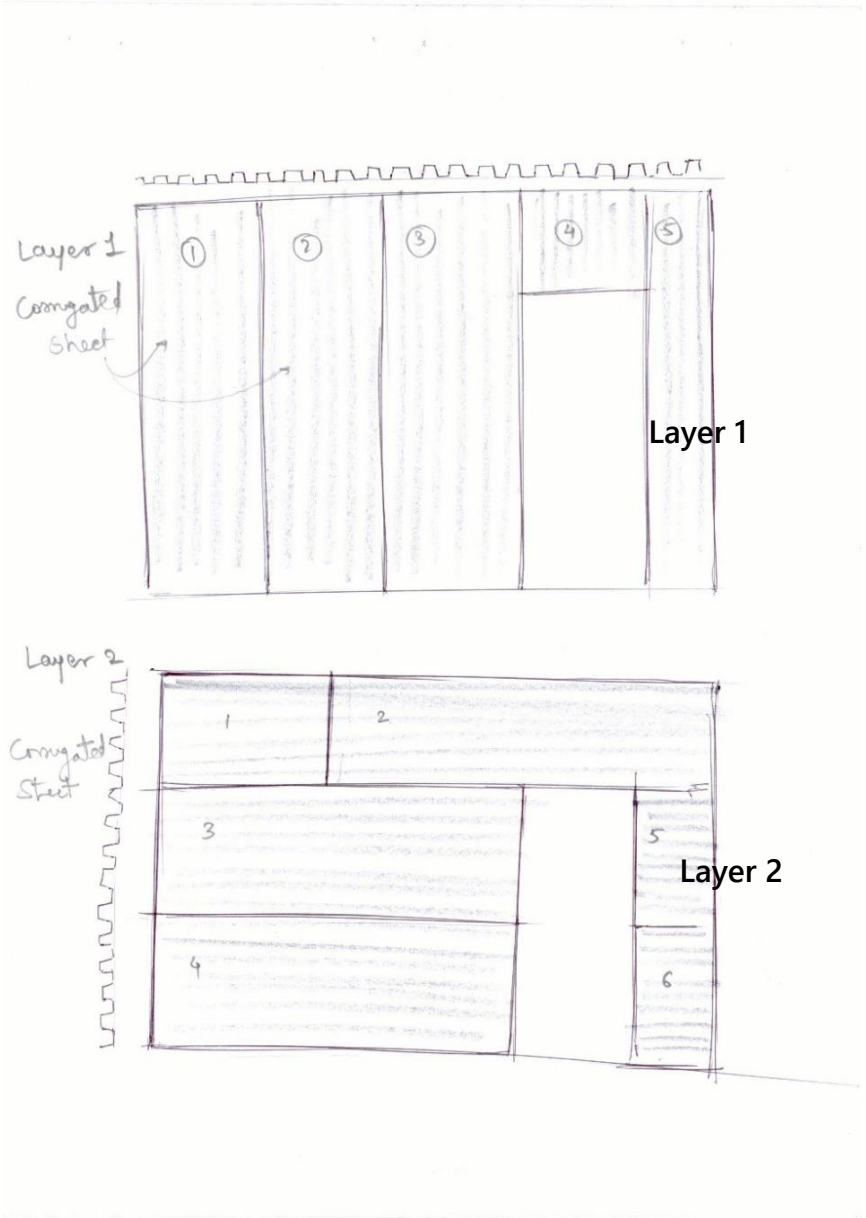


Image 6.5: paper model showing grid for pipe fitting

3. Corrugated sheet is a modular structure, which enables it to construct wall of any size by overlapping the sheets.
4. As the sheets are joined in a criss-cross manner, it creates spaces/ cavities between the corrugation which can be use as a grid for electric and plumbing fittings (fig 6.5)
5. The time required for the construction of wall is very less as compared to normal brick wall.
6. Wall can be constructed on site as per the required size and dimensions.
7. The space created between the corrugations can act as a insulation, which will minimize the heat transfer
8. Panels are light weight can be lifted and moved, it explores the possibilities if movable wall
9. The transportation of the sheets possible by most of the career vehicles.
10. Steel is recyclable and reusable hence After life the sheets will no go to waste.



Corrugated sheet has advantage of construction a wall in a user want. it is very easily achieved by increasing or decreasing the overlap of two sheets.

Different lengths of sheets 2", 3.5", 9" and 10" can minimize the efforts of cutting the sheets.

system need to be developed to calculate the number of sheets required for the wall construction

6.2 Issues To Be Addressed

- To understand the complexity if the wall fitting and installation system a general layout of 600 sq. ft. is drawn and varies aspects are studied. (Fig 6.6)
- The following issues need to be addressed in the steel wall construction

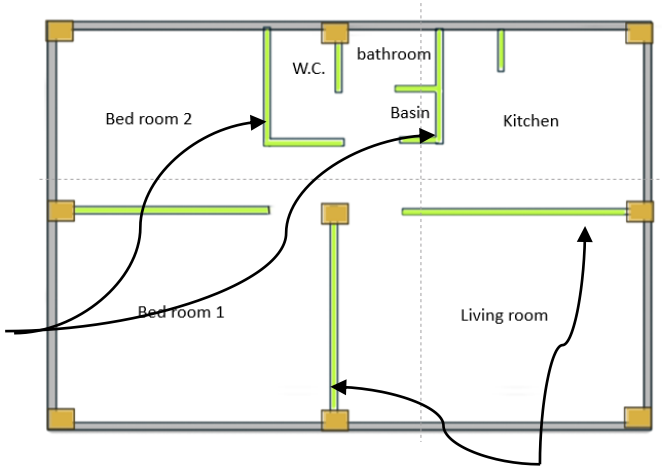


Figure 6.6: Plan of the House

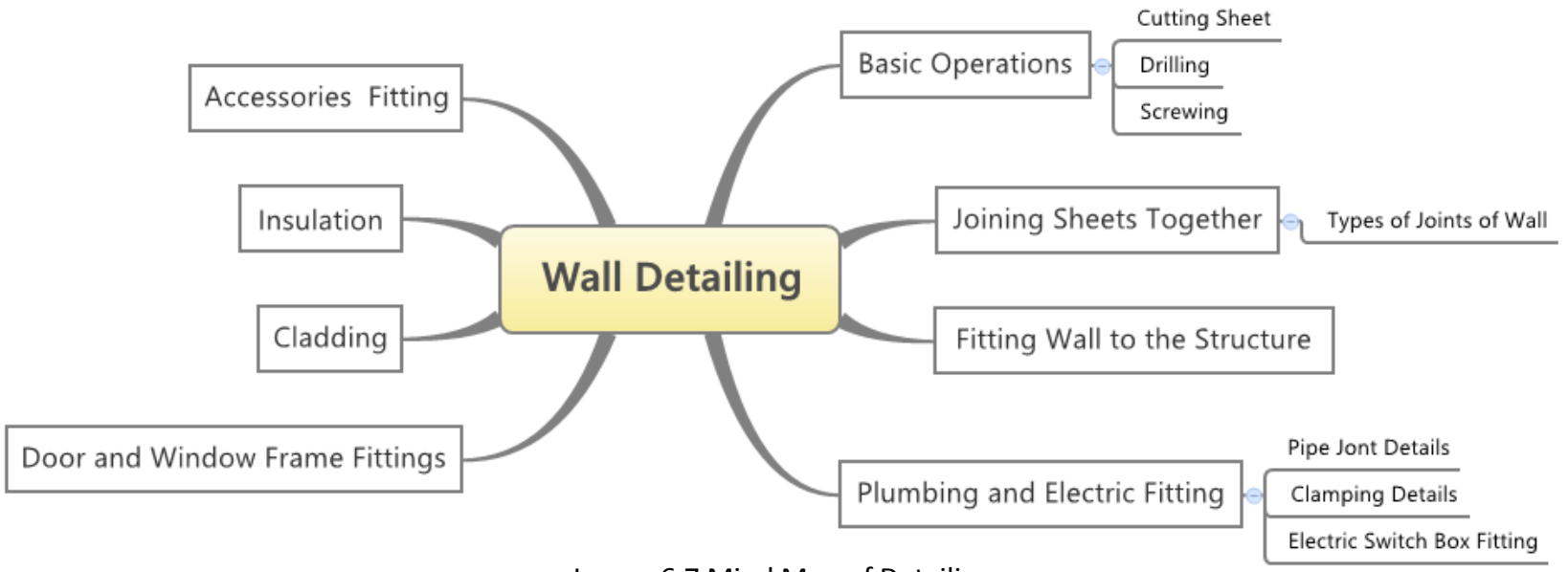


Image:6.7 Mind Map of Detailing

7. Product Detailing

7.1 Requirement

The wall is not just a space diving member of a house for a owner, more than a wall it is a canvas of art which he decorates the way he want., He/she likes to decorate wall the way he want. To make a wall as a complete wall system, many things required to be addressed. It includes wall fixtures, cladding material etc.it also involved the internal consoled features like electric and plumbing fittings. The process of detailing of followed by following process

1. Joining corrugated sheets together
2. Fitting wall panel with the structure
3. Pipe fitting for electric and plumbing
4. Cladding material
5. Door and windows frame fittings
6. Fitting fixtures for wall mountings

7.2 Joining Sheets Together

Selection of method depends on following factors

- Minimum efforts to the user
- Local people should able to do it easily
- Bonding strength
- Time required for the joining
- Area of joint contact
- Machines /tools required
- Access from one side

7.2.1 Nut Bolting

Nut bolting(fig 7.1), screws joint are the most adaptable methods for the sheet metal joining because of their wide range and locally available. For fixing the roofing sheets a special type of rubber cap is used (fig 7.2) which sealed the screw and protects the joint form rusting.

7.2.2 Sheet Metal Joint

Crimping are the most common methods of joining two sheets together. It is a simple cheap, and most widely used (fig. 7.3)

Figure7.1 : Fastening (nut bolt)

Figure 7.2 Sheet Plastic Screw Cover Cap
Source:http://www.ebay.co.uk/sch/Roofing-/66945/i.html

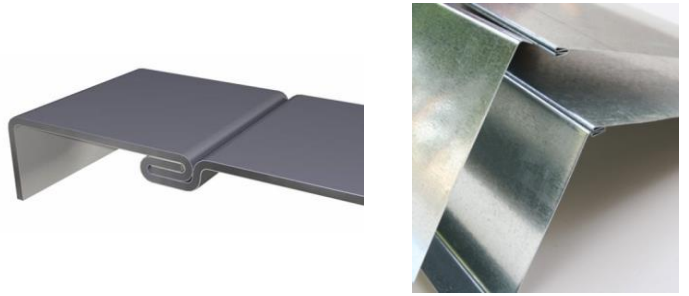


Figure7.3 : Sheet metal joining
Source: http://bansalwiki.blogspot.in/2013/02/sheet-metal-operations.html

Figure7.4 : Spot Welding Machine
http://demo.longlifeweld.com.my/b2b/portable-mini-spot-welder-c-3_16_18.html

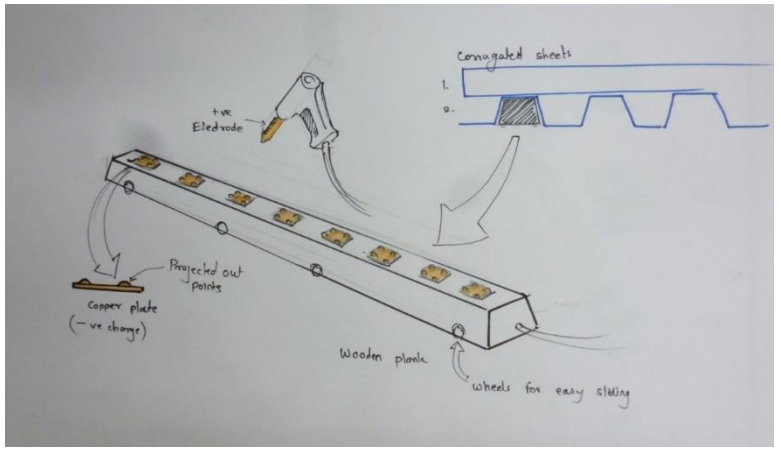


Figure7.4 : Spot Welding Machine Setup for corrugated sheet joining

7.2.3 Spot Welding

Spot is a quick and easy method for joining of a sheets together. It uses two copper electrodes which when in contact generates high amount of heat. Results into a permanent joint of a sheets. (fig7.4). It is most widely used in automotive industry

However there is a limitation with the arm length which needs to be address

Methods for spot welding

To make it easier for the criss-cross joining, the modification in the machine is need to be made.

The one electrode will be placed on the wooden plank in a definite interval and another electrode will be attached to the gun with lever. Advantage of doing this arrangement tis that it within a very short period it is possible to do the activity as in fig 7.4

7.2.4 double Sided Tape

Double sided tapes are the newer technique for joining of a metal parts, 3M company has specially designed a Double Sided tape for joining two sheets with used in most of the automotive industry because of easiness of use and high bonding strength

Figure7.6: DST tape
Source:http://solutions.3m.com/wps/portal/3M/en_US/Adhesives/Tapes/Brands/3M-VHB-Tape/

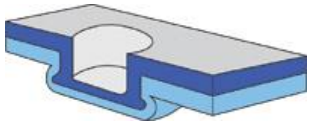


Figure7.6 Detailing of clinching

7.2.5 Clinching

EPS's Round and Rectangular joining systems produce clean, strong and consistent joints in most coated or uncoated metals. The joints are characterized by a "button" formed on the die side layer of metal and a recess formed in the punch side layer. The button is a good indicator of joint quality and therefore, simplifies quality control. Two or more layers of metal typically ranging in thickness from .008"(0.2mm) to .157" (4.0mm) per sheet can be reliably joined in most cases

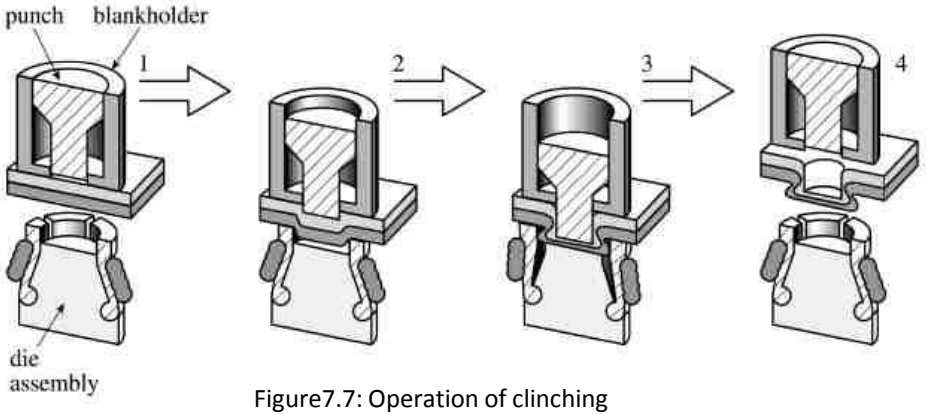


Figure7.7: Operation of clinching
Source: http://www.espclinch.com/JoiningSystems.aspx

Figure7.8 Eyelet
Source: http://www.directindustry.com/prod/rivit/eyelets-58941-415967.html

7.2.6 Eyelet

Eyelet is from the family of rivet uses the same principle of rivet, it has a hole in the middle which enables it to cover a bigger area than normal solid rivet. It is used when a holes are important and need to joined

Image:7.9 Pop-up riveting machine

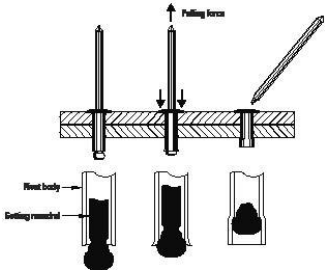


Image:7.10 working of Pop-up rivet

7.2.7 Pop–up Riveting

Pop up rivet is one of the easiest , cheapest way of joining tow parts. Activity involved making a hole on one side riveting using the riveting machine. The greatest advantage is that it is possible to access from one side of the sheet.

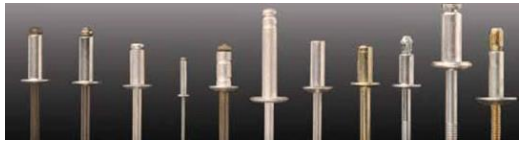


Figure7.11 variety of Pop-up rivet
Source: http://www.ctemag.com/aa_pages/2010/100209_ShopOperations.html

7.2.8 Adhesive Bonding

There are adhesives available for joining the corrugated sheets. Following are the adhesives most widely used for the joining of the corrugated sheets.

Loctite adhesives claiming that their bonding strength is stronger than the spot welds (fig7.14). That can be a good alternative for the joining of corrugate sheets. It rquird special agun for the application as shown in fig. 7.13

The adhesive Loctite H8600 is specially made for sheet metal joints

Another alternative is to use araldite developed by Pidilite Industries

Figure7.13 Adhesive for sheet metal joining

Figure7.12 Adhesive for sheet metal joining
Source: http://i1.adis.ws/i/washford/301850?pd_zoom

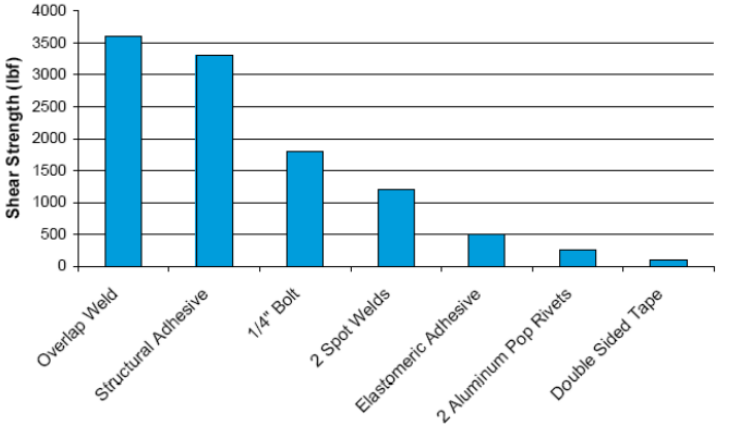
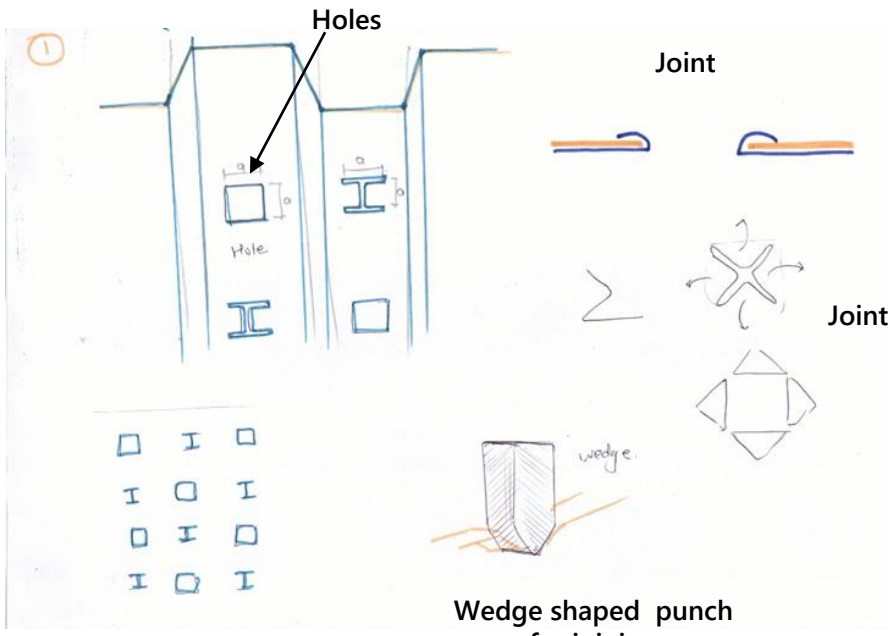
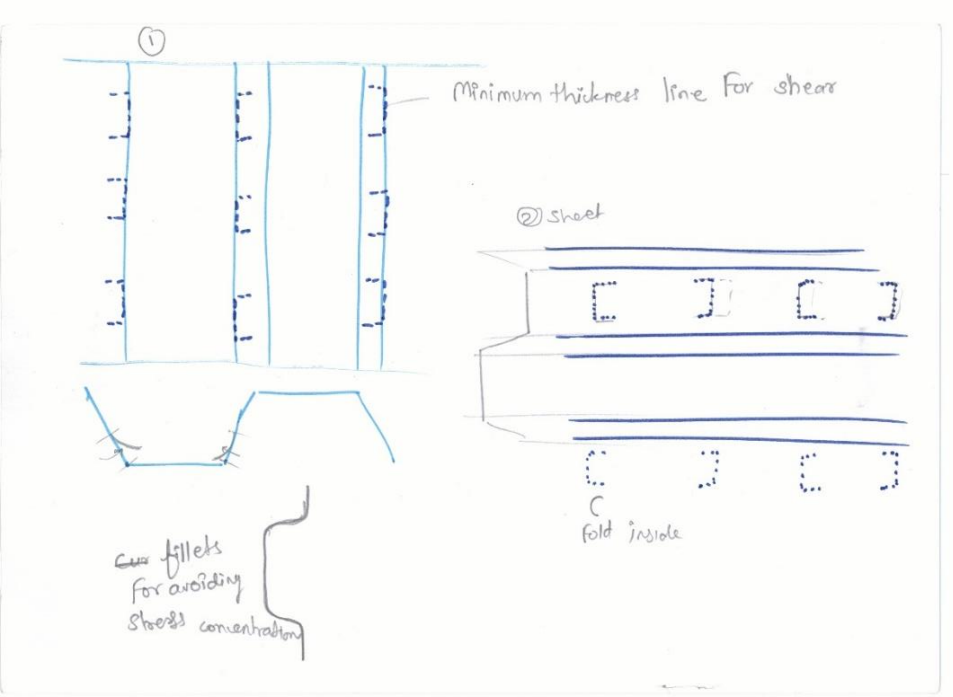


Figure7.14 Shear strength of the various assembly methods
Source:http://multimedia.3m.com/mws/media/312885O/3m tm-vhbtm-tapes-design-guide.pdf

7.2.9 Other Way Of Joining





In this method of joining the square hole and I section hole is cut in to the sheet. The joint is obtained by expanding the I hole into the square hole by using a wedge

In this process cuts are made on the side wall of the corrugate sheets so that plate will bend inside and the joint is obtained

7.3 Fixing Wall Panel To The Structure

After joining corrugated sheets it is required to fit it with the

The corrugated sheets will be joined on the ground then will be lifted to fit the structure. Fitting can also be carried out by joining panel by panel to the structure.

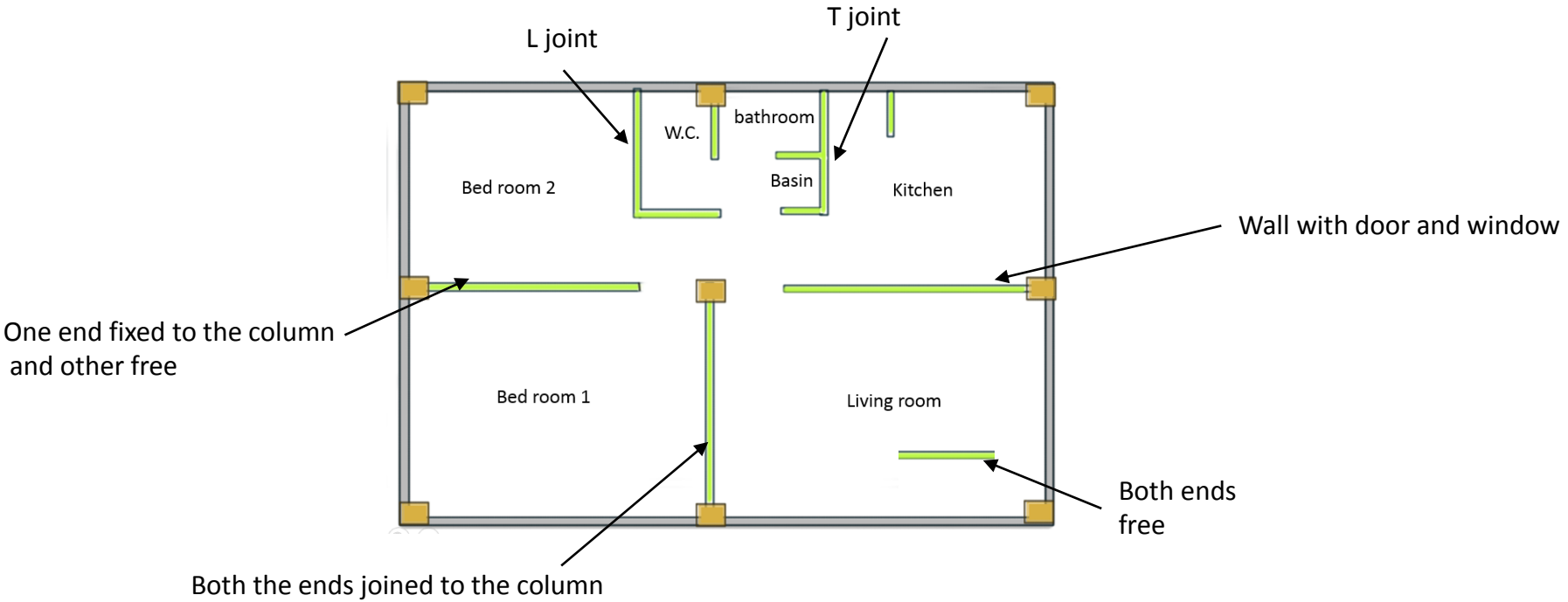
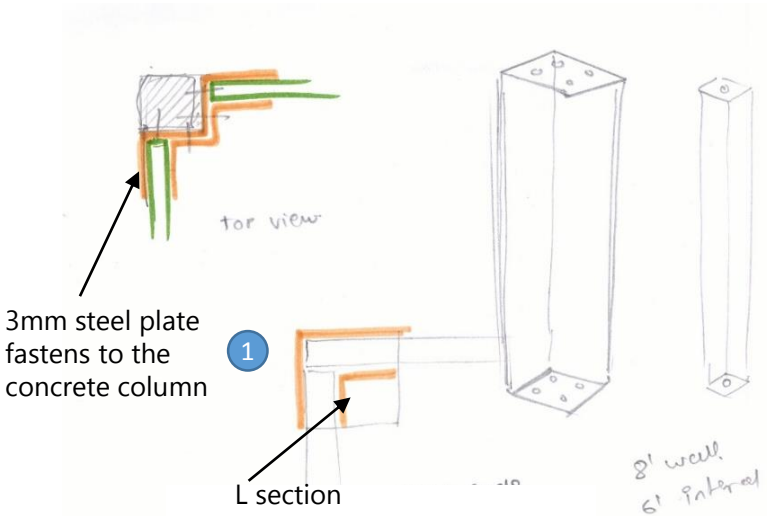
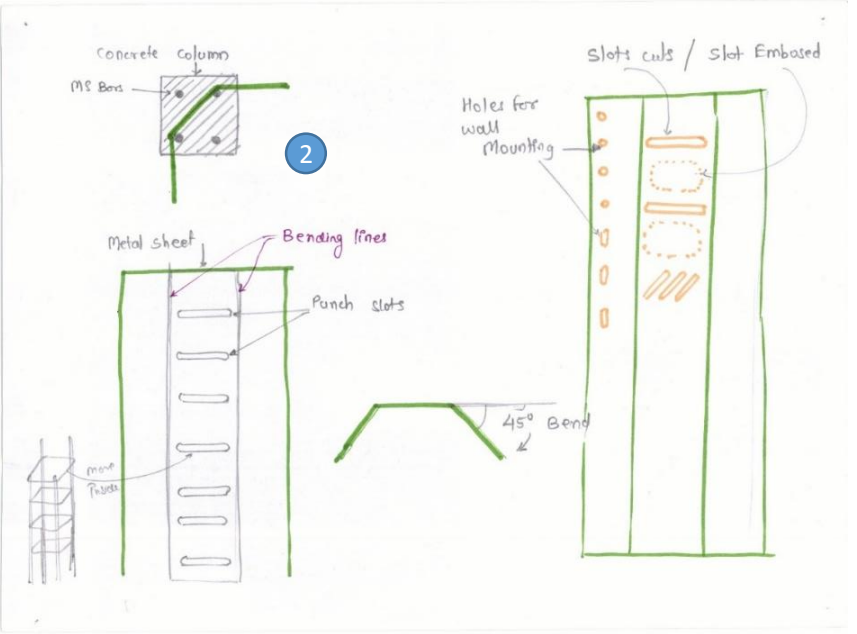


Figure 7.15 Wall Detailing

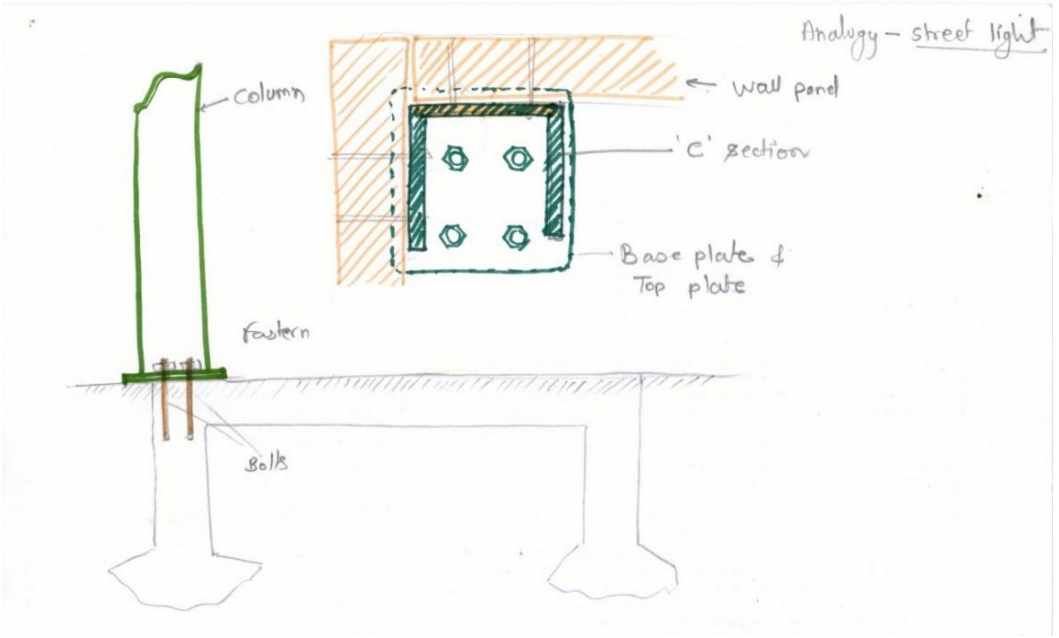


Wall panel joining to the concrete column

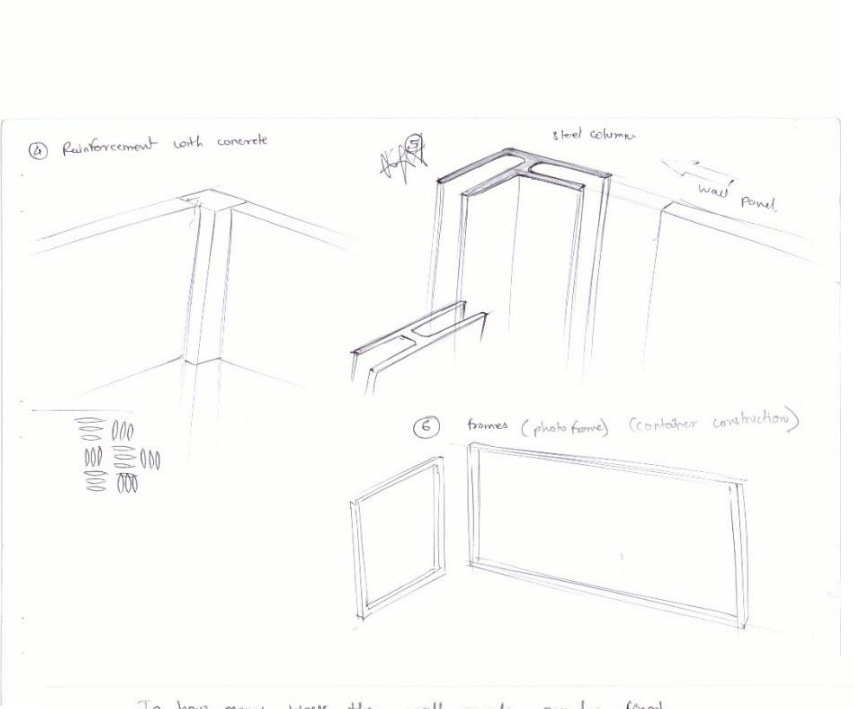


(1) This method of joining wall with the concrete structure consist of a metal plates which will be fastened to the concrete structure with the help of foundation bolts and the wall panels will be joined to these joints with the help of nut-bolts.

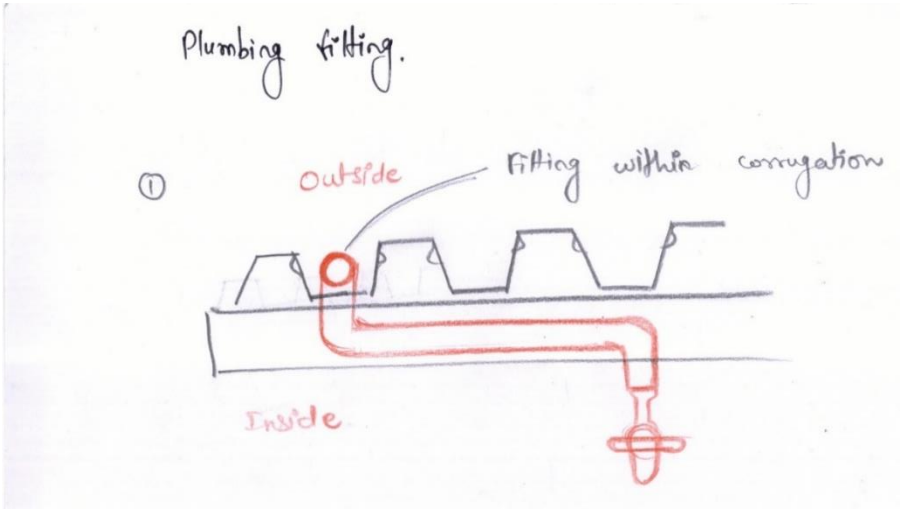
(2)The idea is to reinforced the metal plate inside the concrete structure itself for the fastening with wall panel. for firm grip the reinforced part can be made grooves and embossed to reduce slippage of metal sheet.

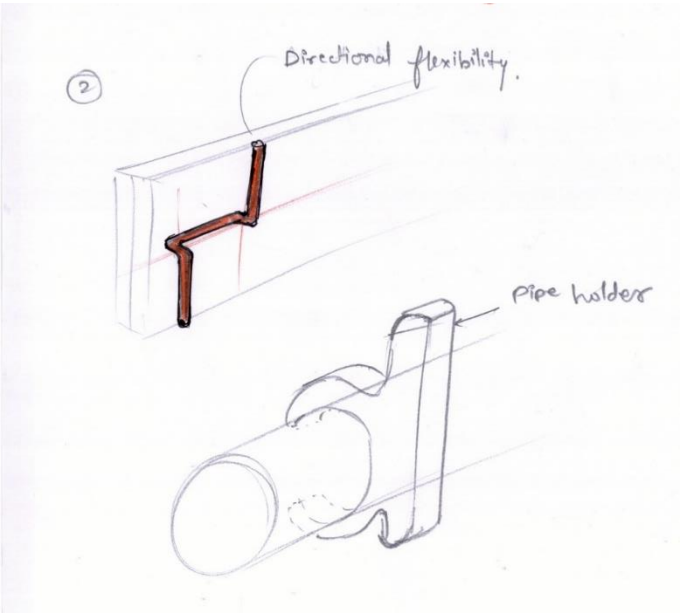


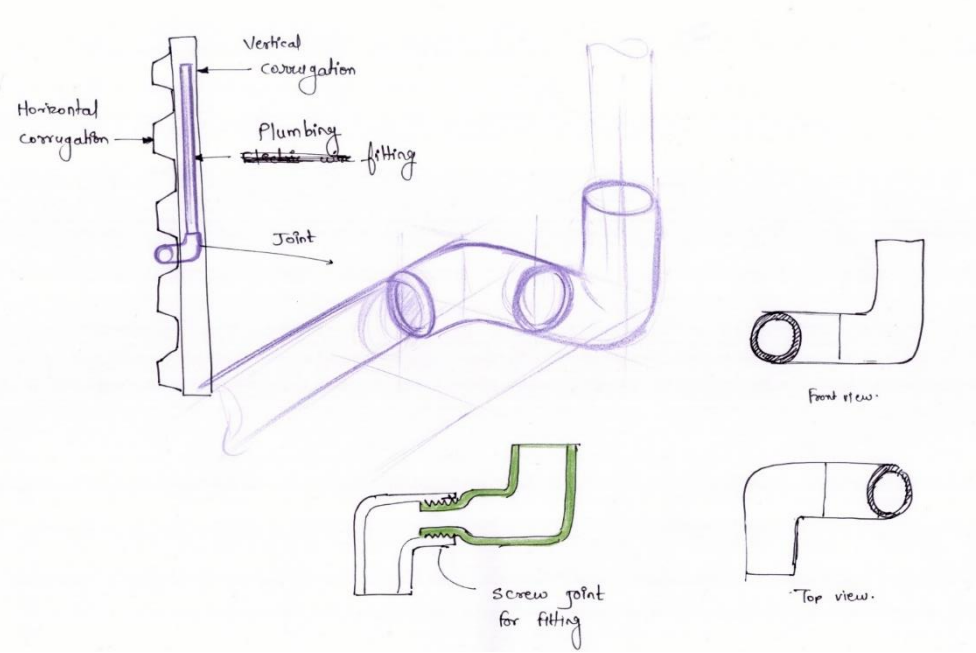
Wall panel joining to the C section column
which is fixed to the structure

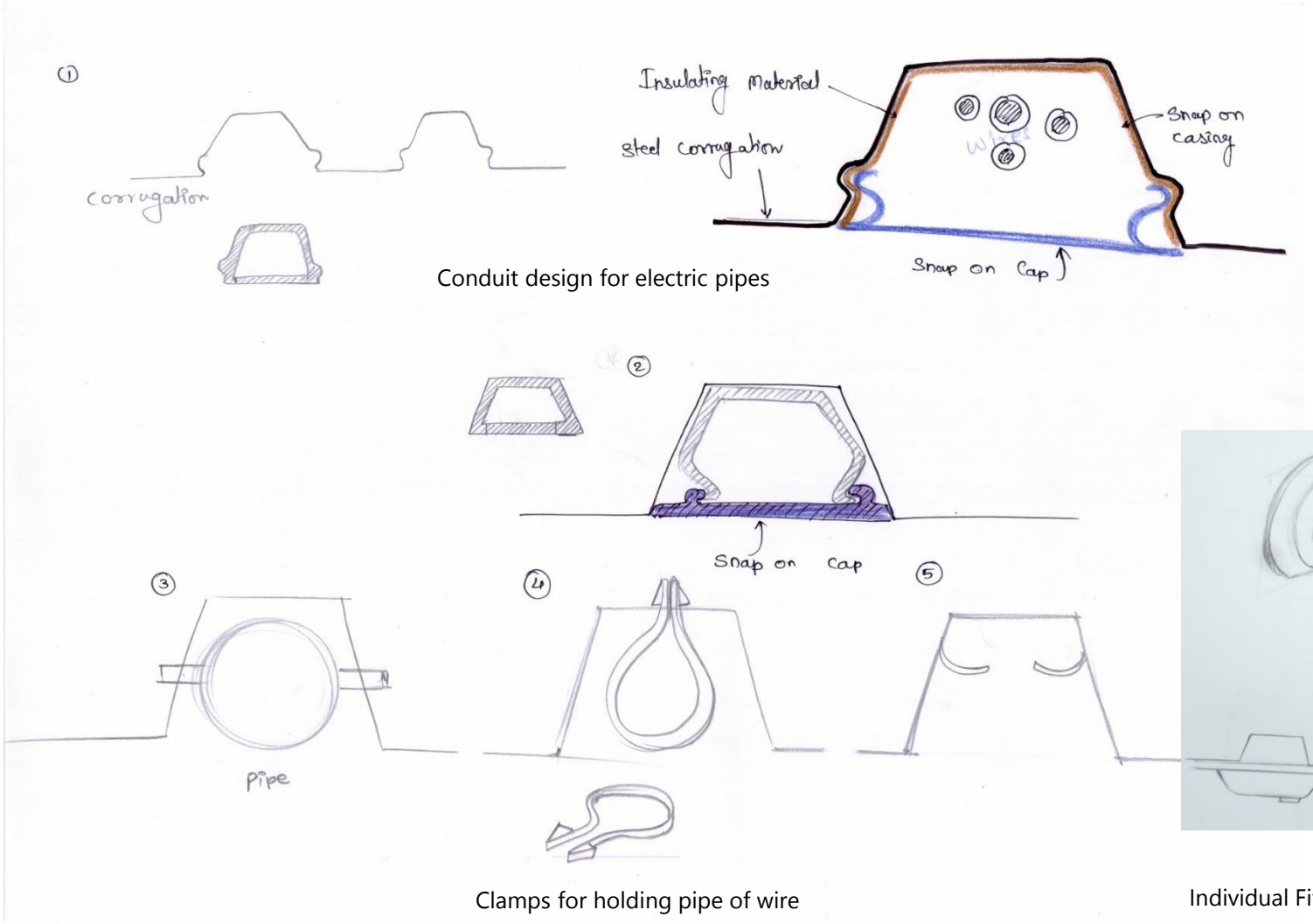


7.4 Plumbing Fitting Details



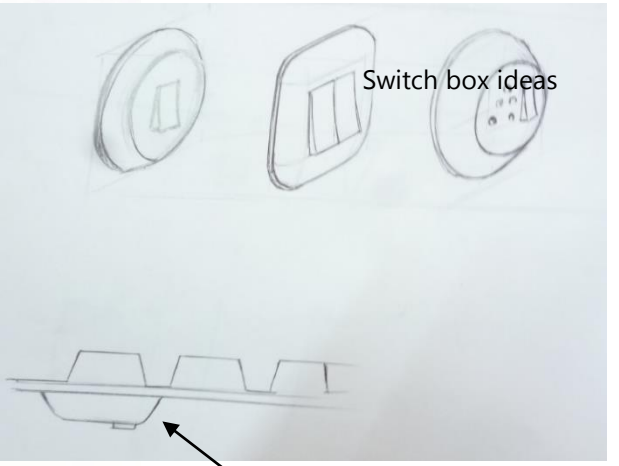






Conduit design for electric pipes

Clamps for holding pipe of wire



Switch box ideas

Individual Fitting into a individual corrugation

7.5 Cladding Material

Various studies on material through market survey and web research is carried out to find the suitable material for cladding.

Following are the most common materials based on:

- Ease of installation
- Economy
- Sound isolation
- Heat isolation
- versatility
- durability
- Painting, wallpaper
- Sustainability
- Water resistance

Material are

- MDF
- Plywood
- Gypsum board
- Bison board
- Phenolic board
- PVC wall panels

The most suitable cladding material decided is the plywood of 6 mm or 3 mm thick depending upon the requirement of the user. It is very easily available, easy to nail, saw, join by adhesive, satiable for putty painting, which makes it most suitable material for cladding. The reason of choosing 6 mm thick is that the majority of strength comes form the corrugation structure

To join cladding material to the structure the following details found very useful than traditional screws.

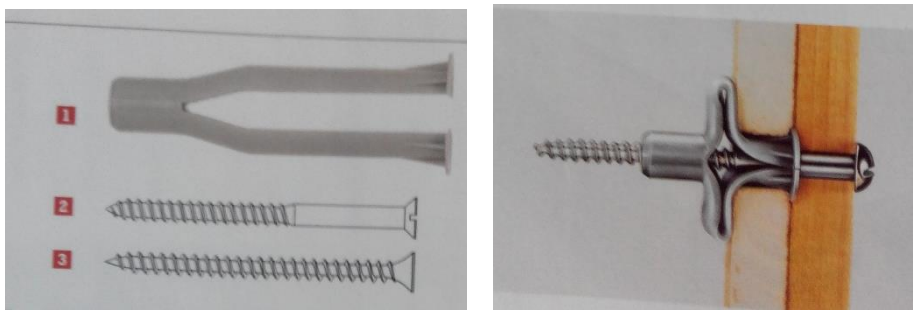


Figure 7.16 clamp detailing for fitting
Source http://www.onesystems.com/pdf/education/Concrete-Anchor-Installation-Instructions-for-NAT.pdf

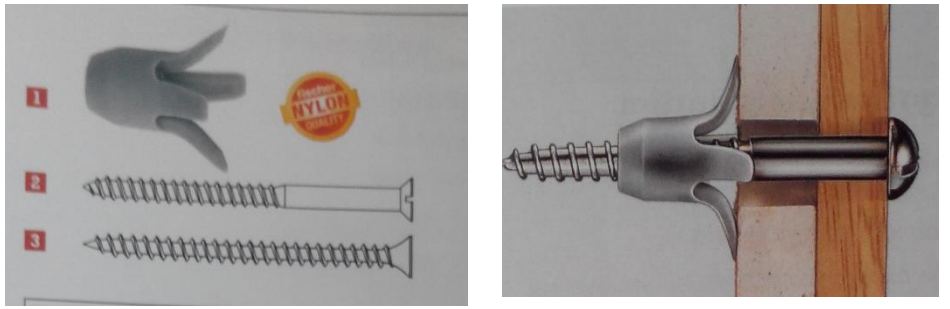
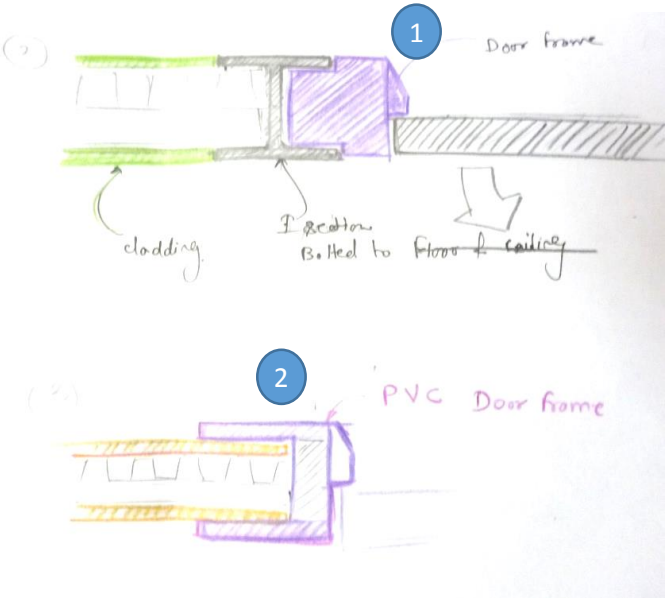
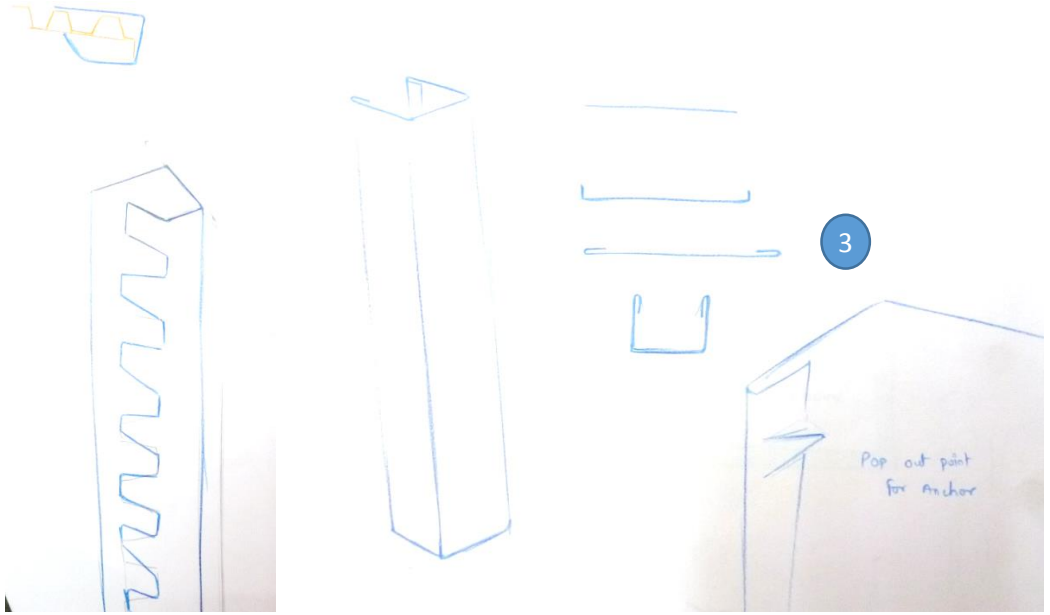


Figure 7.17 clamp detailing for fitting
Source http://www.onesystems.com/pdf/education/Concrete-Anchor-Installation-Instructions-for-NAT.pdf





7.6 Door And Frame Fittings

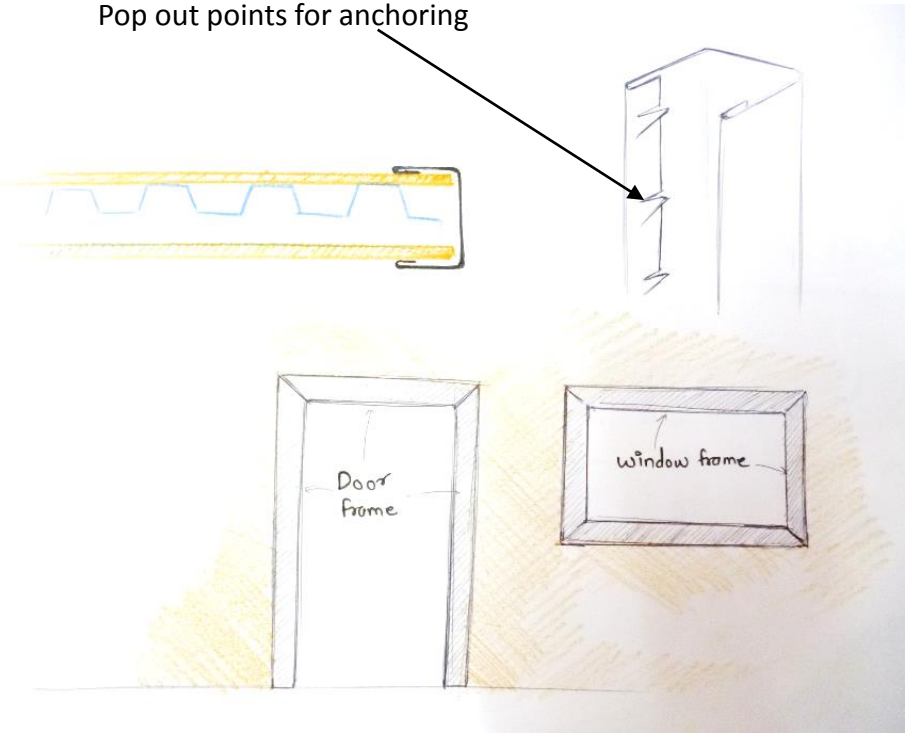
1. Ideation

Window and door fittings required frames on which the hinge goes and allows them to move. For that frames has to be string and rigidly fixed to the walls.

The various fixing details for frame are detailed out here. In (1) the frame is made out of a wood screwed by I section in between, holding both wooden frame and wall panel together. Wooden frame are traditional in Indian context and most widely used.

PVC doors and windows are new and offers better water and chemical resistant properties. Use of PVC with the shape as shown in fig (2) can be helpful for making frames which can be screwed directly on the wall panels.

The another exploration is made with the sheet metal itself. Bending sheet as per the door profile and clamp it to the wall panel with screws will can be made possible. It will just to insert component will save space and screws on both the sides can hold it in place. Wooden plank can be provided in between to give space for screwing hinges.



door and window frame

Inspired from ravel plug the small pointed out protrusions can be made for string anchoring. These protrusions are basically projected out pointed ends which will get anchored in the cladding material such as MDF or plywood. This eliminates the excessive use of screws for fixing the frame. It act as a snap fit joint.

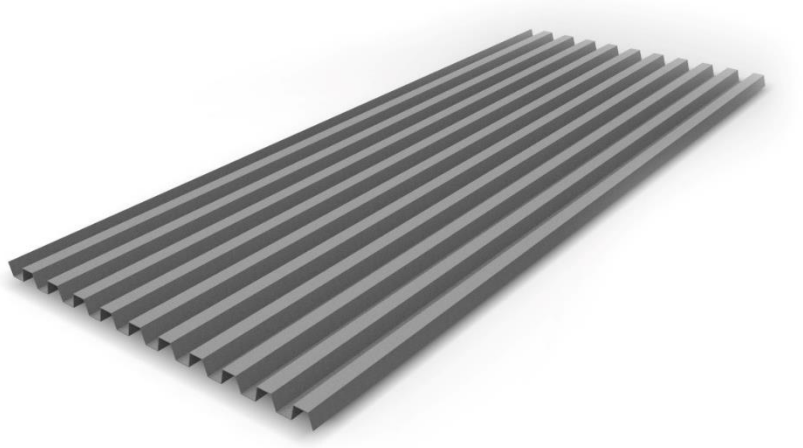


Image: Corrugated sheet panels with trapezoidal corrugations

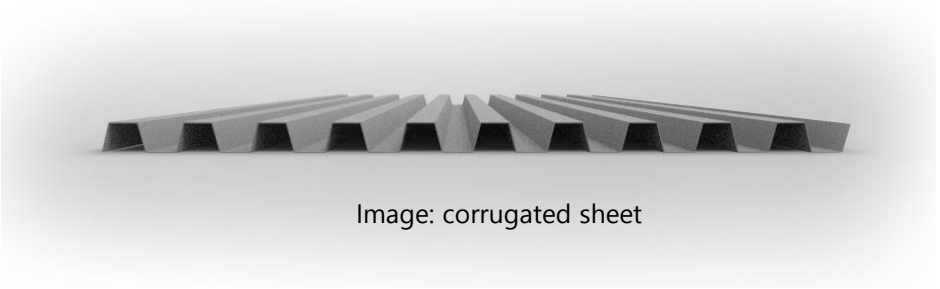


Image: corrugated sheet

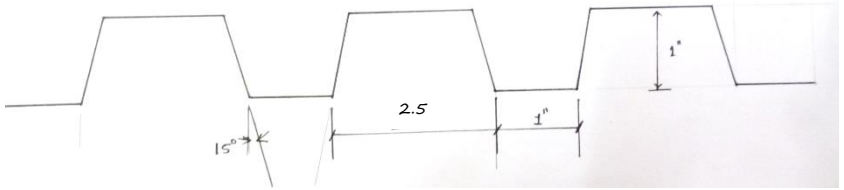


Image: corrugated sheet size

Final concept

Final dimensions
3.25ft x 10ft x 1ft in height

Corrugation size
-1" width of corrugation
-2" space between two corrugations

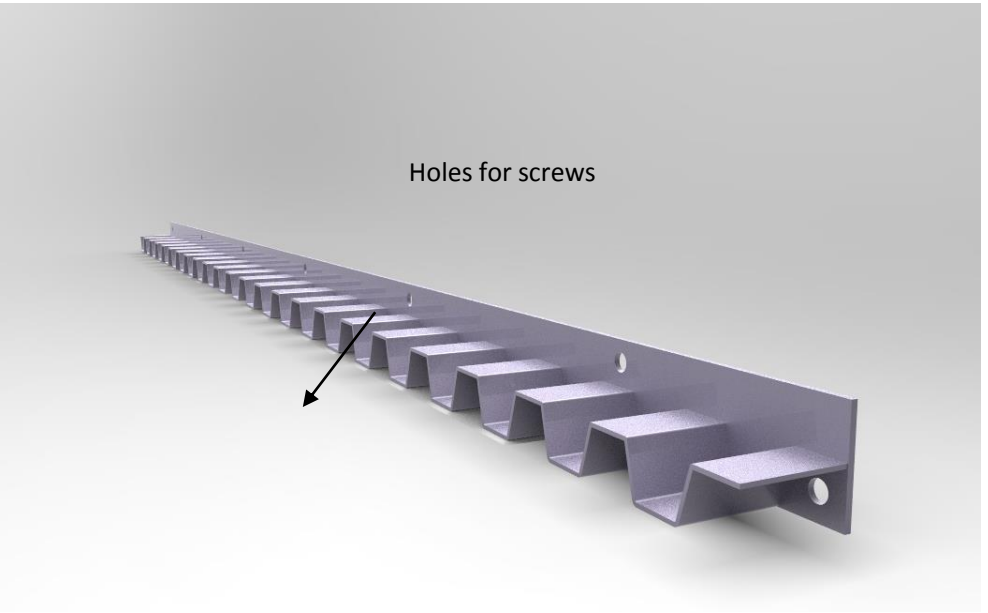
Factors considered
Strength
Access for joining
Transportation
Minimal wastage of material
Minimal cutting
2 dimensional growth
Space for pipe fitting
Space for switch-board
Doors and windows fittings

Fitting to the structure details

The fitting detail shown in the figure will be fix to the column structure and the corrugated wall panels will we screwed to the joint

This panel will be fixed to the structure by bolts and the corrugated sheet will be joined over that.

It has the replica of the corrugation which allows to make face contact for joinig.



Plu

Image: redesigned ‘Elbow’ (left) existing ‘Elbow’ (Right)

The final plumbing details are shown in the image. The problem of changing direction of pipe is addressed here. The activity analysis done on fitting pipes. Same details are applicable for electrical pipes also

Image: redesigned ‘Tee’ (left) existing ‘Tee’ (Right)

Image: Problem for fitting

Image: Solution male female joint

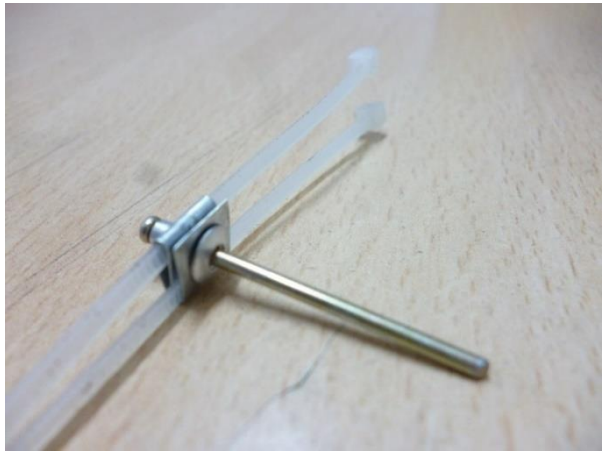
Clamping detail

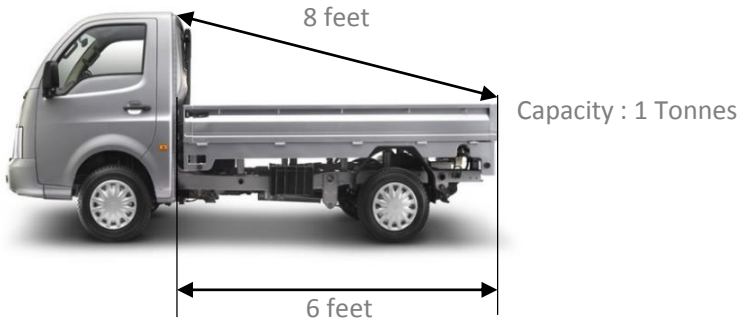
In order to hold pipe in place some suitable way of clamping is necessary .keeping in mind corrugation and space constraints, simplest detail of clamping is developed

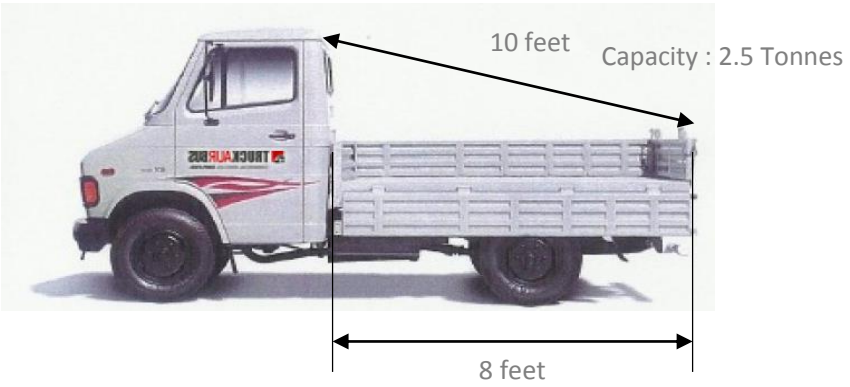
This detail involved a one way strap hold between thin GI sheet with pop up rivet place in between.

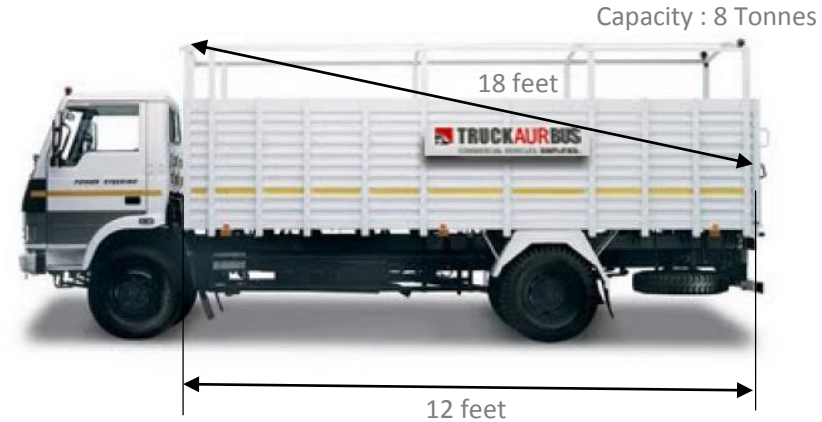
Direction of use:

- Drill a hole with drilling machine on the corrugation
- Join the clamp to the corrugated sheet
- Place the pipe in place and tie the strap









: Images8.1 of Trucks with there load carrying dimensions and capacity

Source : www.tatamotors.com.bd www.truckaurbus.com

8. Activity Analysis

Based on the inputs from the guide and field experts, it is found that, there will be issues with activity which is need to be solve. This included in the final design brief to solve the problems of the user so that the fabrication activity can be studied and simplified for the local user.

8.1 Transportation Consideration

Consideration of transportation involved transport of the material , accommodation of the defined size, access for maximum number of vehicles and most common vehicle types.

The longest part is of size 10 feet, which can be very easily transported through the following sizes of trucks.

Fig 8.1 shows the smallest t pick up ruck available in India name as TATA Ace. It has a load carrying capacity of 1 tonne and it is very common mode for the transportation in India. The length of the bed is 6 feet long so the longest part of size approx. 8 feet can easily be placed in the truck.

Middle one is the TATA 407 which is the most widely used for the transpiration. Followed by Eicher trucks amoungs popular once.

8.2 joining of corrugated Sheet

Overlapping sheets

marking

support for drilling

Punching

Drilling hole

Removing Support

Joining by nut bolt

Image 8.2 activity of joining corrugated sheets

8.3 Plumbing Fittings

Figure 8.5 Saw cutter for drilling

Figure 8.6 Pipe Holding Strap

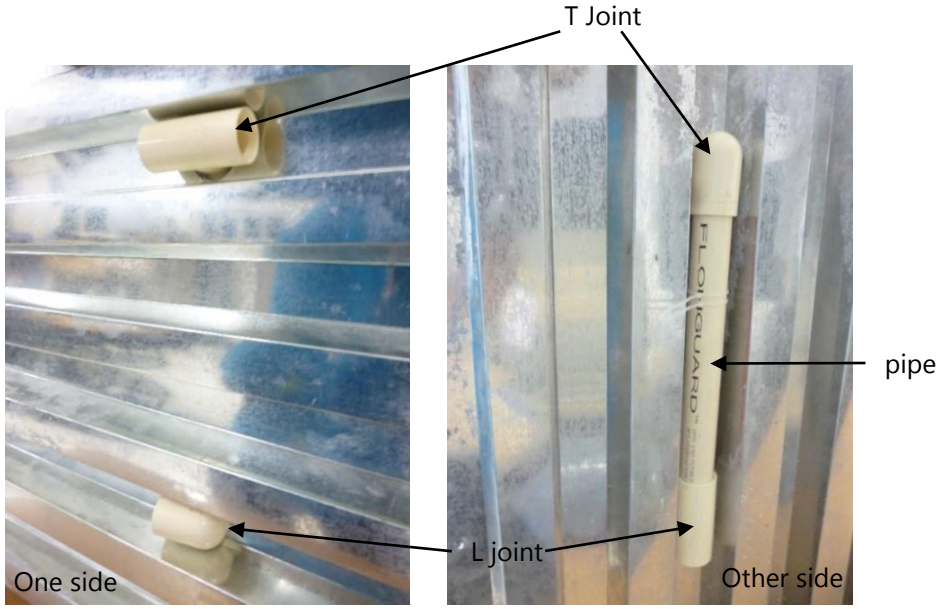


Figure 8.7 Final Joint

While doing the activity of plumbing the issue come up is to fit the 'T' and 'L' joints into to the corrugations because of limited space (Fig. 8.3). The issued is solved by making it into a split joint as shown in figure 8.4.

Image 8.3 insertion of T joint into the corrugated sheet

Figure 8.4 Split T joint

The hole required to drill in the corrugated sheet can be very easily drilled by suing circular saw cutter as (fig 8.5) which are available in different standard sizes.

The sample fitting of the plumbing pile is shown in figure 8.7. because of spaces in between the corrugation the pipe can very easily fits into the space

The clamming for the pipe can be achieved by pop-up strap

Concept Testing

As the Technical calculations is not the part of the project, the testing of the concept is done by taking advice from the experts from field of engineering. For this, Meetings and discussions with the faculties form the various departments including Mechanical, Structural, Civil and Energy Science of IIT Bombay were conducted and based on collective feedback a simple test of deflection is conducted on 1:1 model

For deflection testing a panel of 10 ft. X 10 ft. is made by crisscrossing the corrugated sheets.

The sheet is allowed to rest in supports as shown in the figure 8.8 and deflection of the is measured with the veneer calliper at the centre. The amount is figured out to be 8 mm approx. which has build up confidence for the final product

Figure 8.8 Strength testing for bending

9. Cost Estimation

- Cost calculation of corrugated sheet
- Thickness: 0.5 mm
- Height of corrugation: 25mm

- Volume of steel required:
- Hypothesis
- Cost of transportation of the material is not included here.
- Plumbing and electric fitting cost is not included here
- **Corrugated sheet**
- Cost of corrugated sheet with size 10ft X 3.5 feet
- =900 rs per sheet for 0.5 mm thick
- **Cladding material**

  Plywood standard quality 4 ft X 8 ft 3/4 inched thick

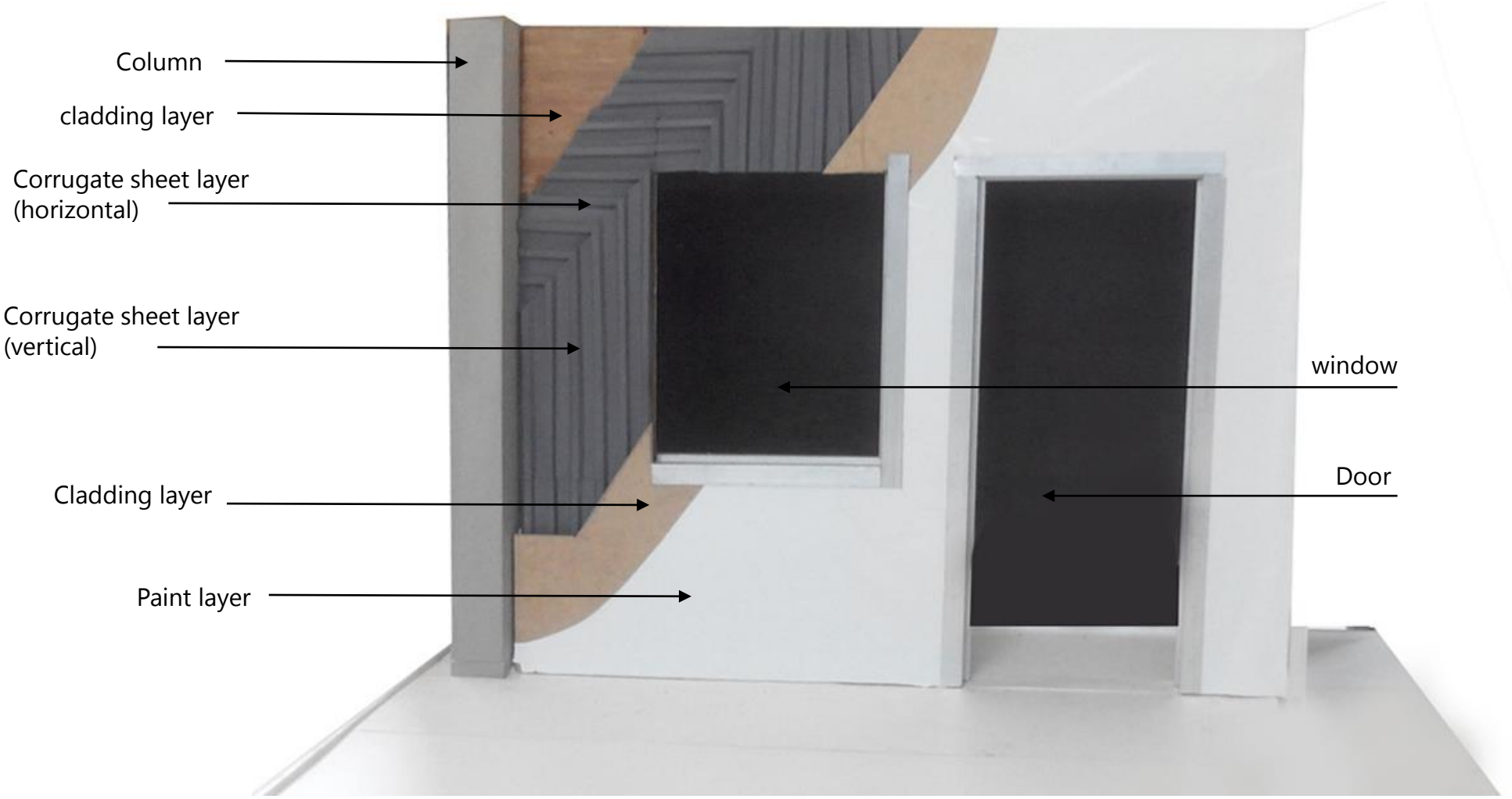
  =600 rs per sheet
- Total plywood required = 6.5 sheets X 600 = 3900 apprx

- Corrugated sheet size

  10 feet *3.5 feet *0.5mm * 6 sheets =1000* 6 =6000.00
- Plywood 10*10 *2 sides = 3900.00
- Joining of two sheets (250nut bots) = 500.00
- Joining of cladding = 200.00
- Joining with the structure = 200.00
- Labour cost = 1000.00

Total **=11600.00**

10. Prototype



1:5 scaled prototype model showing sections of wall layers

11. Conclusion

It is possible to two directional stiffness by joining tow corrugated sheet in cross direction. Any size of wall in the interval of 6" can be easily built by overlapping corrugations. The strength of the wall comes from the crisscross arrangement of corrugated sheet of 0.5mm thick.

Following conclusions are derived from the corrugated sheet wall system.

- 25% cheaper and 80% quicker to fabricate compared to a regular brick wall.

- Requires lesser skills and number of the labourers.

- Zero water consumption during fabrication.

- About 66% lighter as compared to a normal brick wall.

- Criss-crossing creates spaces/cavities between the corrugation, good for electrical and plumbing fittings.

- Sheets will not shatter, helpful in saving lives during any natural disaster .

- No water usage during the construction.

12. Future Scope

The criss-cross corrugation system can be use in disaster management also. It has potential to be deployed in very less amount of time with small single room structure. Detailing can be incorporated of a 'L' section for the joining of the two panels at right angle.

It has potential to be a load bearing member of the house which can help to build column less house. Appropriate testing and engineering analysis needs to be done to prove its strength.

The scope of criss-cross corrugations is not just limited to the internal wall only, it can be use as the external wall of the house also with appropriate treatment for thermal insulation, sound isolation and weather proof coatings.

13. References

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15. http://solutions.3m.com/wps/portal/3M/en_US/Adhesives/Tapes/Brands/3M-VHB-Tape/