# Debre Markos University


## Debre Markos Institute of Technology

### School of Civil and Water Resource Engineering

### AC/Program of Construction Technology and Management


# Course Material for Cost Efficient Construction/ COTM 5281


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# Chapter 1
# Introduction

## 1.1. Concept/theory

The United Nations estimates that at least one hundred million people in the world have no home. If those with poor quality housing are included, the number is more than one billion. And the news only gets worse; as the total number of homeless is growing (Worldwide housing needs are expected to double over the next 50 years. In Africa alone, they are expected to grow more than threefold.)

Construction costs in Ethiopia are increasing dramatically. Due to inflation rates getting into double digits, the construction costs have registered a similar increase, primarily due to cost of basic building materials such as steel, cement, bricks, timber and other inputs as well as cost of labor. As a result, the cost of construction using conventional building materials and construction is beyond the affordability of the economically weak and low-income groups of population as well as a large cross section of the middle - income groups.

Therefore, there is a need to adopt cost-effective construction methods either by *upgradation of traditional technologies using local resources* or *applying modern construction materials and techniques* with efficient inputs leading to economic solutions. This has become the most relevant aspect in the context of the large volume of housing to he constructed in both rural and urban areas and the consideration of limitations in the availability of resources such as building materials and finance. Low cost or affordable construction technologies and materials are often touted as a panacea in meeting the ever growing demand for rapid housing delivery in developing economies.

Affordable housing is a term used to describe dwelling units whose total housing cost are deemed "Affordable" to a group of people within a specified income range. Affordable housing policies seek to house as many people as practical at the lowest cost, leading in the past to overcrowding.

Despite a preference to preserve traditional building methods, economic considerations often override. Affordable housing for the poor is often consigned, with disastrous consequences, to areas that are the least suitable for building, such as steep mountains, refuse tips and unstable soils. Whilst affordable housing often incorporates relatively low standards of construction, this is a practice that should be avoided. Affordable housing must be engineered to provide for cyclonic wind load, landslip, expansive soils and subsidence as appropriate.

The rural populations of Ethiopia live largely under difficult conditions dominated by poverty and lack of access to knowledge on alternative, appropriate construction technologies that can exploit local resources leading to a low–cost construction.

In addition, building regulations and the standards invoked therein vary from country to country. To a large degree they tend to concentrate on the design and construction of large buildings, and, in many countries, they either do not apply to or are not enforced for the bulk of cheaper low-rise (usually single storey) housing.

There is an array of technology options available for various elements of building construction, leading to cost-effectiveness and at the same time not effecting the performance characteristics expected from a decent house. It is desirable to have increased understanding of the various materials and technology options, its structural and functional characteristics and efficiencies and more importantly the methodologies for implementation. Series of follow-up measures to enable application of the same would need to be taken. These would cover work related to regulatory measures, organizational development needs and also technology transfer mechanisms evolved. This would play a major role in ensuring the adoption of appropriate and cost-effective technologies in housing and building construction scene, which is one of the vital inputs to make affordable and acceptable housing a reality for the vast majority of low-income people.

### 1.2. Importance/Objectives

The investigation of the production of local materials and alternative technologies of "low - cost" construction houses aims at:-

- To take advantage in a sustainable and ecologically acceptable way the local resources for the production of alternative construction materials;
- To promote the production of local construction materials and alternative constructive systems that are popularized and disseminated within Communities, Educational Institutions and in the Professional Training Centers;
- To contribute to the creation of regulations of alternative constructive systems and uniformity of the method and quality of the local production materials.

## APPLICATION AREAS

The following are the possible application areas of low-cost construction:

- Land cost should be kept to a minimum.
- Compact design.
- Community buy-in to the housing process from the start.
- Location of project should be close to existing bulk services.
- Maximum utilization of space inside house.

- Implement measures to reduce your overheads cost (enough human resources on site).
- Buy material in bulk and Good house design (simplifies construction, saves time and resources).

The following should be taken in to account in cost effective housing:

- Where practical, affordable housing should reflect the architectural style of the area in which it is to be located. However, this should not restrict the adoption of variations and improvements to suit structural requirements and changing aspirations of the occupants.
- Affordable housing should be designed and constructed in accordance with local building regulations and standards. Where these are not adequate, international standards should be used.
- Particular attention should be paid to design for cyclonic wind loading, earthquake loading and unstable foundations.

**Strategic plans:**

i. Selection and evaluation of materials and processes.
ii. Up scaling and modernization of home-grown production technologies
iii. Selection, evaluation and establishing economics of emerging methods of construction
iv. Economy and efficiency in housing/building construction projects
v. Strengthening technology dissemination and demonstration capabilities.
vi. Training and skill upgradation including entrepreneurship development.
vii. Field level applications of innovative building materials and construction technologies in mass housing projects.
viii. Use of bamboo in housing and building construction
ix. Vulnerability reduction, risk assessment and disaster resistant construction.
x. Technology Transfer

## 1.3. Low cost = Low energy

The building materials industries as a whole rely to a large extent on high temperature processes and are among the most energy-intensive industries. For example, the cost of energy in the production of cement or clay bricks/tiles accounts for 50 to 70 per cent of the direct cost of manufacturing. It is therefore, important that the use of energy in the production process is optimized so that overall cost of building construction is reduced and the polluting impact of the excessive use of fossil fuel is arrested. According to Van Wyk, construction activities consume 50% of all resources globally, 70% of all global timber products and 40% of energy. The consumption of these resources adversely affects the environment through over-exploitation of both renewable and

nonrenewable resources (materials and energy).
The creation of low-energy ecological habitats is a key component to sustainable development. The design of the housing and the use of the materials have to correspond to local building traditions and to the user group's way of living. The concept of sustainable development has drawn interest from built environment professionals, as the construction industry is considered to have a significant impact on the environment.

As the developed world adopts low-carbon footprint housing systems this sets in motion a paradigm shift from the obsession of steel and concrete, towards a realization that communities are already endowed with natural resources it is the beneficiation knowledge systems which remain largely untapped.

Another important but often neglected component in energy consumption in the building-materials sector is in relation to transportation or distribution of the finished product for construction. Building materials are produced solely for construction so that their energy consumption computations can only be finalized at the point of use. In fact, there are some developing countries where the cost of transporting building materials outweighs the actual cost of production. In Botswana, Honduras and Sudan, after 150 kms, the cost of transporting cement is higher than the manufacturing cost.

Even though the task of reducing use of energy, while maintaining high quality and quantity of outputs, is rather difficult, measures could be taken to monitor and optimize the use of energy in the production process. Ultimately, the most promising approach would be to increase the use of low energy-content materials and apply energy-efficient and low-polluting technologies in the industry.

Cost-effective construction technologies can bring down the embodied energy level associated with production of building materials by lowering use of energy-consuming materials. This embodied energy is a crucial factor for sustainable construction practices and effective reduction of the same would contribute in mitigating global warming. The cost-effective construction technologies would emerge as the most acceptable case of sustainable technologies in terms of cost and environment.

Contribution of the building industry to global warming can no longer be ignored. Modern buildings consume energy in a number of ways. Energy consumption in buildings occurs in five phases. The first phase corresponds to the manufacturing of building materials and components, which is termed as embodied energy. The second and third phases correspond to the energy used to transport materials from production plants to the building site and the energy used in the actual construction of the building, which is respectively referred to as grey energy and induced energy.

Fourthly, energy is consumed at the operational phase, which corresponds to the running of the building when it is occupied. Finally, energy is consumed in the demolition process of buildings as well as in the recycling of their parts, when this is promoted. We have found that the cost-effective and alternate construction technologies, which apart from reducing cost of construction by reduction of quantity of building materials through improved and innovative techniques or use of alternate low-energy consuming materials, can play a great role in reduction of $CO_2$ emission and thus help in the protection of the environment.

Production of ordinary and readily available construction materials requires huge amounts of energy through burning of coal and oil, which in turn emit a large volume of GHGs. Reduction in this emission through alternate technologies/ practices will be beneficial to the problem of global warming. To deal with this situation, it is important to accurately quantify the $CO_2$ emissions per unit of such materials.

**Table 1 Energy Consumption of Some Construction Materials**

| | ***Classification of material*** | ***Energy consumption in MJ/Kg of material*** |
|---|---|---|
| I | Burnt-clay tiles | 3 |
| II | Burnt-clay bricks | 1.43 |
| | Hollow-concrete blocks | 1.20 |
| | Sand-lime blocks | 1.03 |
| III | Reinforced concrete | 2.00 - 8.00 |
| | Unreinforced concrete | 1.20 |
| | Aerated concrete | 2.89 |
| IV | Portland cement | 6.70 |
| | Hydrated lime | 4.21 |
| | Gypsum plaster | 1.52 |
| | Calcined-clay pozzolana | 1.39 |
| V | Steel | 26.00 |

| | | |
|---|---|---|
| | Aluminum | 144.00 |
| VI | Wood products | 3.00 |

Source: Fog, M. H. and Nadkarni, K. L.

**Table 2 Cost of energy relative to production cost of selected materials**

| **Material** | **Energy cost as percentage of total material cost** |
|---|---|
| Cement | 43.0 – 53.0 |
| Lime | 47.9 – 59.5 |
| Gypsum products | 11.1 – 16.6 |
| Bricks and tile | 29.7 – 36.5 |
| Other structural | 23.7 |
| Clay products | 35.2 |
| Concrete blocks | 3.6 – 6.5 |
| Timber sawmills | 2.2 – 4.1 |

**Table 3: Energy consumption in materials for walling**

| **Element** | **Energy content of lsq. M in MJ** | | |
|---|---|---|---|
| Wall made of hollow-clay bricks, 18cm x 10cm x 30cm 21cm thick | Bricks: | 118.0KG | 278.5 |
| | Cement | : 2.5Kg | 10.0 |
| | Lime: | 6.4Kg | 57.6 |
| | Sand: | 0.043m3 | 314.2 |
| | | | 360.3 |
| Wall made of hollow-clay bricks, 8cm x1 8cm x 30cm 13cm thick | Bricks: | 73.1KG | 172.5 |
| | Cement: | 2.0Kg | 8.0 |

| | | | |
|---|---|---|---|
| | Lime: | 5.2Kg | 46.8 |
| | Sand: | 0.035m3 | 11.5 |
| | | | 238.8 |
| Wall made of solid-clay bricks, 12cm x16cm x 25cm 15cm thick | Bricks: | 127.0KG | 660.4 |
| | Cement: | 1.8Kg | 7.2 |
| | Lime: | 4.5Kg | 40.5 |
| | Sand: | 0.03m3 | 9.9 |
| | | | 718.0 |
| Wall made of solid-clay bricks, 12cm x16cm x 25cm 30cm thick | Bricks: | 255.0KG | 1326.0 |
| | Cement: | 4.4Kg | 17.6 |
| | Lime: | 11.1Kg | 99.9 |
| | Sand: | 0.074m3 | 24.4 |
| | | | 1467.9 |
| Wall made of adobe, 40cm x10cm x 20cm 43cm thick | Adobe: | 800.0KG | 1.5 |
| | Cement: | 1.6Kg | 6.4 |
| | Lime: | 4.2Kg | 37.8 |
| | Sand: | 0.028m3 | 9.4 |
| | | | 55.1 |

# Chapter 2
# Planning and low cost design

## 2.1. Integrated planning

Building construction basically involves four stages including conceptual, preliminary design, final design and execution. Cost minimization could be achieved through close and serious consideration at all stages. **Conceptual Stage** At the conceptual stage coordination among professionals is very crucial. The following professionals could be involved in the design:

- Architect
- Structural Engineer
- Sanitary Engineer
- Electrical Engineer
- Electro-mechanical engineer
- Sociologist
- Others (Environmentalist,)

**Preliminary and Final Design Stage**

Examples of design areas where cost effectiveness through material quantity modulation could be achieved during preliminary and final design stages:

❖ **Substructure**

**Mat foundation:** Upper part of mat foundation can be used as a ground floor element. This could save
the cost of ground floor slab construction.

**Isolated Footing:** Volume concrete could be reduced by adopting an optimum shape of a footing. (b and c types need lesser volume of concrete in Fig 1)

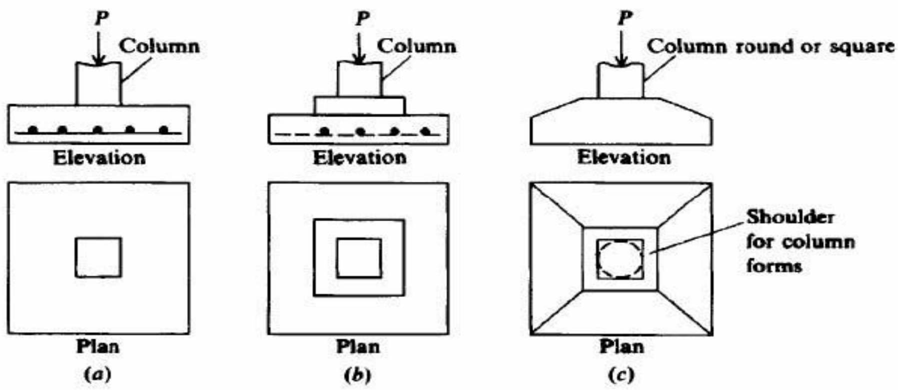


Fig 1 Possible isolated footing types

**Combined Footing:** Trapezoidal type needs lesser volume of concrete and reinforcement steel if the geometrical conditions and loads allow (Fig 2).

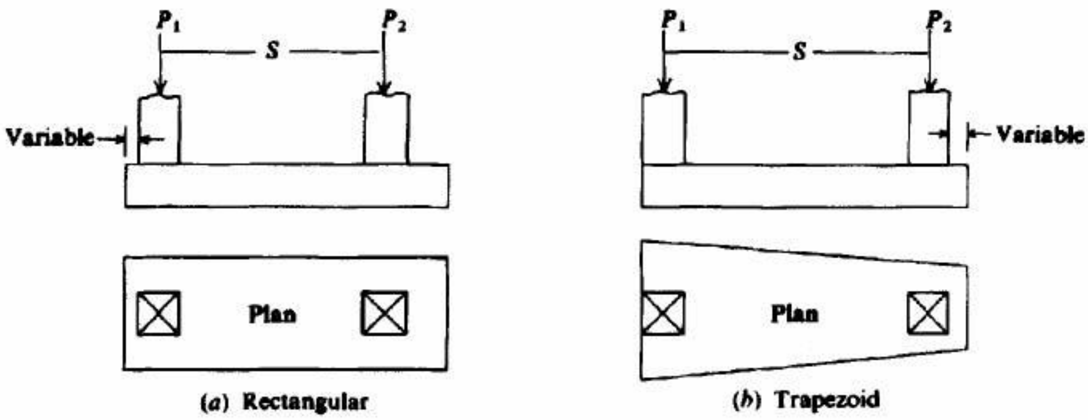



Fig 2 Possible combined footing types

**Preliminary and Detailed Design:**

Preliminary and detailed design involves:

- **Geometry and planning** Simple geometry with minimal re-entrant angles minimizes external wall length while maximizing area. Similarly simple roof geometry minimizes junctions and materials. Planning to reduce circulation space can maximize the usable area of a home and minimize wasted space.
- **Single or multi-storey** Single storey construction is always cheaper than two storey because of the cost of scaffolding and transporting materials. Floors above ground are always more expensive than floors on ground because of the extra beams and support required. Above ground slabs require considerably more reinforcement and form working than slabs on ground.
- **Simplicity and Repetition** The use of simple structural elements repeated throughout a project can reduce the overall cost as design and set-out need only be done once. Duplicating elements can reduce costs because fabrication can be done in bulk.
- **Economies of Scale** The larger the order, the lower becomes the cost. Generally medium to large construction projects are more economical, per sqm, than smaller ones.
- **New or existing work** Building new is always cheaper than alterations and additions because of the rectification work involved and because of the unknown complications in retaining existing work.
- **Number of amenity areas** Kitchens, laundries and bathrooms are more expensive to fit-out

than other rooms because of the intensive use of plumbing, electrical and gas services as well as intensive use of fixtures, fittings, wet area treatment, tiling and joinery items. A good way to reduce cost is to minimize the number of amenity areas.

- **Amalgamating services** Locating bathrooms kitchens and laundry's etc adjacent or above each other, can reduce the cost of providing services (particularly plumbing) as the length of concealed pipe work and conduit is reduced. Similarly amalgamating several services in the same trench or duct can reduce costs.
- **Low cost building systems** Generally the cheapest building system is the traditional method because the skills and materials are readily available; however, building systems that reduce the use of materials and or save in construction time can provide a significant savings. The only risk is that the longevity of new systems cannot always be verified.
- **Standard dimensions** Many building products come in standard dimensions. Designing with this in mind can reduce cutting and wastage. Fabricated components such as aluminum windows and doors come in standard sizes. Standard sizes are always cheaper than custom made sizes.
- **Prefabrication** Fabricating items in a factory is always faster and cheaper than on site. This is because there is not always a good supply of shelter, materials, specialized machinery and labor on site. The extent of prefabrication can range from individual components, right up to a totally prefabricated home.
- **Speed of Construction** A building construction method that is faster not only utilizes labor more efficiently but also reduces the daily on-site costs such as building foreman, fencing, scaffolding, site services, insurances etc.
- **Variations** Whilst it may be undesirable to avoid all variations, they should be minimized if you want to reduce the cost. Variations to a building contract not only amount to the cost of altering the work, but attract an additional percentage cost to cover builder's site attendance and coordination. Variations may also extend the construction time.
- **Accuracy of Documents** The completeness and proper coordination of contract documents, including consultant's documents, can be an important factor in the cost of construction because it can affect the accuracy of tendering and the likelihood of changes to the design or variations to the building contract.

## 2.2. Detailed planning

- *Adequate time and information should be available to perform detail planning and design*

Examples of details design aspect which results in low-cost construction:

- Increasing the quality of concrete/steel – needs benefit/cost analysis

- Reinforcement cuts : in beams and slabs (proper reinforcement cutting schedule)
- In high rise buildings lower story columns have higher load carrying capacity => they might not need much increased section (concrete, steel)
- Steel truss systems: all members need not be of the same cross section, proper orientation of members

## 2.3. Documentation

It is always important for the designers to make sure that their design ideas are properly conveyed to the ones who would be executing project. Therefore, documents prepared during design should be clear enough so that ambiguities are avoided during the actual construction phase.

The following is list of some of the documents produced by the designers:

- Drawings including details
- Models
- Statical Calculation Reports
- Technical Specifications
- Bill of quantities
- Work schedules
- (Contract Documents)
- (Guide Lines and manuals)

# Chapter 3
# Material

## 3.1. Introduction

While awareness about the critical need for more affordable housing has grown, the solutions have not. Building materials accounts for nearly 60 to 65% of the cost of house construction. With the constant rise in the cost of traditional building materials and with the poor affordability of large segments of our population the cost of an adequate house is increasingly going beyond the affordable limits of more than 30-35% of our population lying in the lower income segments. This calls for wide spread technology dissemination and availability at decentralized locations of cost-effective building materials and construction techniques.

The five leading modern construction materials are cement, concrete, steel, bricks and wood. In the industrialized world, these have been used to build more comfortable housing than ever before. This has contributed to changing living patterns of the middle class, but not for the poor. Steel and cement are symbols of wealth and power - but many people cannot afford them.

Low cost building materials do not mean sub-standard materials, but the materials available/developed locally, cutting the transportation charges and manufactured applying civil engineering know-how for better service and economy.

The various building materials available can be divided into two types and they are:

**Traditional materials**

These materials serve the basic needs of the majority of the population. These have very useful properties; however, there is a scope to modify these through appropriate changes in the process of production as well as in the techniques of application, so that these are made structurally and functionally acceptable.

**Conventional materials**

The conventional materials are those, which have been obtained by using the modern technologies and can be mentioned as fruit of research and adopted to indigenous requirements.

## 3.2. Alternative Construction Materials

### 3.2.1 Mud

During post earthquake reconstruction, mud houses are most effective since they are environmental friendly, cool in summer and warm in winter. Mud is only a material available everywhere in abundance free of cost and is being used as building material from centuries. But such types of houses are temporary in nature, prone to erosion by heavy rains. The disadvantages of mud can be overcome by suitable improvement in design and construction techniques.

The strength of mud is improved by adding cement, lime, bitumen or fibers and it also becomes resistant to water, its main enemy. Cement stabilized mud blocks, using 3 to 10% cement by weight molded in mechanical machines are better than adobe mud bricks.

### 3.2.2 Cement and Concrete Substitutes

With 1 $m^3$ produced per year per capita, concrete is the most widely used material in the world and accounts for 5-8% of man-made $CO_2$ emissions. It is possible to reduce its environmental impact by substituting cement with

Supplementary cementiteous materials (SCM's) like fly ash, slag, silica fume and natural pozzolana. Calcined Cuban clayey soils are an interesting SCM for low-cost housing projects which promote the use of locally produced and affordable "eco-friendly" materials in developing countries, where the energy costs of producing cement make it disproportionally expensive. Investigations have shown that fly ash produced as an industrial waste from thermal power stations can safely replace up to 20 per cent by weight of normal Portland cement.

Mass concrete has good thermal capacity but not as good as earth building and masonry. Hollow concrete blocks often used in residential construction have poor thermal capacity especially in comparison to what they replace – bricks, stone, earth. While concrete may be necessary for large buildings and can be the most appropriate material for some components, e.g., floor slabs, there is much to gain in most residential building jobs from promoting local materials, assembled according to local technologies, by local workers.

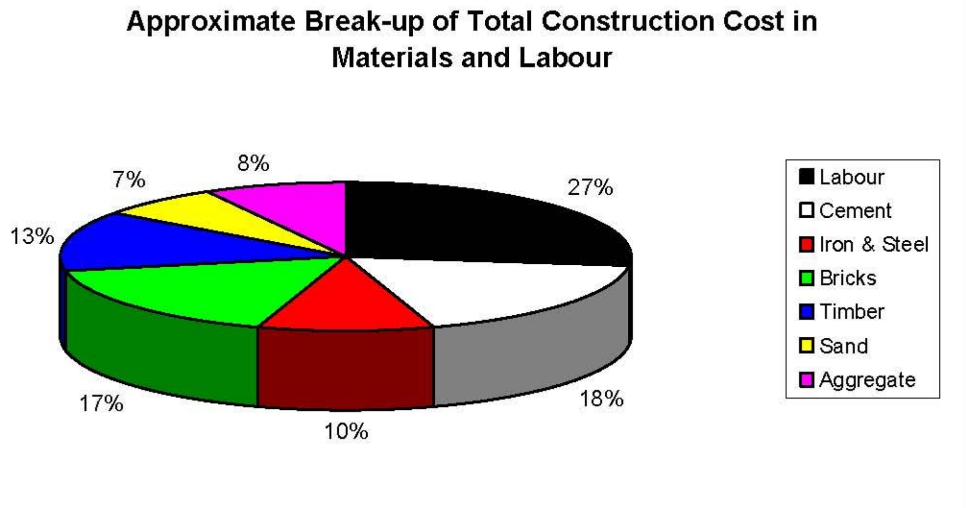
The uncritical assumption that concrete is best should be laid aside in favor of a more open-minded approach to technologies viewed for their own merits and their ability to be improved and adapted for modern urban life. A palette of materials including rammed earth, brick, stone, wood, bamboo, and many other indigenous materials should be added to by developing new cement-based materials and major improvements in the finished quality of concrete through better quality control.

### 3.2.3 Wood/Timber Substitutes

Continuing dependence on conventional building materials like burnt clay bricks, cement, steel and primary timbers from natural forests is neither possible nor desirable without detriment to environment. Though their application in field has yet to achieve the desired level, however, it is amply demonstrated that by their increasing application it is possible to conserve non-renewable materials, reduce pollution and achieve substantial savings in energy consumption.

| Materials | Energy for production MJ/Kg | Weight per volume Kg/m$^3$ | Energy for production Kg/m$^3$ | Stress when in use | Energy for unit stress |
|---|---|---|---|---|---|
| Concrete | 0.8 | 2400 | 1920 | 8 | 240 |
| Steel | 30 | 7800 | 234000 | 160 | 1500 |
| Wood | 1 | 600 | 600 | 7.5 | 80 |
| Bamboo | 0.5 | 600 | 300 | 10 | 30 |

*Source: Prof. J. A. Janssen, Eindhoven University, The Netherlands*




### 3.2.4 Alternative Walling Materials

The materials used for walling for instance can consist of:

- Mud
- Sun-dried bricks

- Rammed earth
- Stabilized soil blocks
- Kiln-burnt bricks
- Timber/bamboo
- Stone block masonry
- Precast/factory-made walling units using light weight cellular concrete
- Concrete hollow blocks
- Ferro-cement

Mud, sun-dried bricks and rammed earth can be used extensively depending on the availability and quality of existing soils. Stabilization of soil is done by stabilizers like cement, lime, asphalt, and molasses. With the strength of kiln-burnt bricks being of the order of 40 to 200 kg/sq.cm it is possible to use single brick load-bearing walls of up to five storeys. Half brick thick zigzag pattern load bearing walls can also be used. In addition, adoption of "Modular" bricks can effect savings in the use of brick and mortar.

Stone-block masonry is an R & D contribution using stone blocks and lime/cement mortar, made by semiskilled labor. In places which area seismically active, the conventional system of timber, bamboo, mat-based wall system can be employed. (This system is called "Ekra" walling and is a traditionally popular and structurally sound walling system). With appropriate R & D inputs, it is possible to give plaster over cladding material with stretched wire mesh and appropriate frames of timber or reinforced cement concrete.

Factory made cellular concrete wall panels have been used in some places. In situations where it is not possible to have access to masonry building blocks made of local materials, recourse has to be taken to manufacture masonry blocks. This could cover aerated light weight concrete blocks and hollow concrete masonry blocks.

The hollow concrete block masonry can be used both as structural/non-structural elements. Large prefabricated panel units have been used in mass construction schemes. However, its application in the country might be limited mainly due to the limitations in lifting/erecting equipments as well as weaknesses in joints of wall to wall and roof to wall interaction locations.

Hollow concrete block masonry has been able to make a major impact lately, primarily because of the poor quality of burnt brick and also high cost of the local fuels namely timber and coal for burning kilns. In some areas, most of the houses constructed by co-operative societies, private builders are taking recourse to use hollow concrete block masonry for walling. Fly ash which is a waste emanating from thermal power plants can be utilized with advantage for either fly ash-based bricks or aerated light weight blocks.

### 3.2.5 Alternative Roofing Materials

Reinforced cement concrete (RCC) roofing slabs are predominantly used in many housing projects more so in the urban context. But the use of the many economic alternatives can play a major role in large housing projects.

The various alternative systems that can be used are:

- Clay/micro-concrete tiled roofing with insulation over timber/ferro-cement rafters
- Stone roofing with distributors
- Corrugated sheet: asbestos, galvanized iron (GI)
- Prefabricated brick panel
- 'L'panel roofing
- Filler slab roofing with various filler material
- Clay tile - RCC batten roof
- Pre-cast cellular concrete roofing unit
- RCC channel units
- Pre-cast joist and hollow block construction
- Pre-cast RCC solid planks/joists
- Funicular shells over edge beams
- Pre-cast plate floors
- Ferro-cement roofing elements
- Filler slab roofing with various filler material

Using prefabricated roofing elements, large-scale housing projects can be constructed economically.

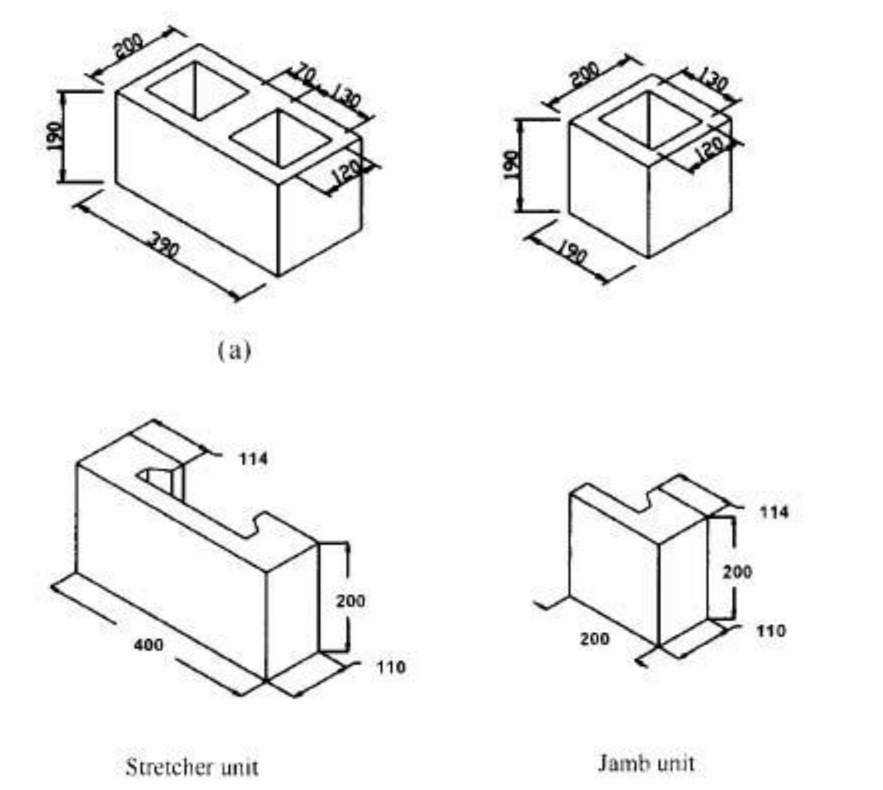
### 3.2.6 Doors and windows

Timber is used for door and window frames and shutters and also for structural and non-structural walling and roofing units. With a view to effect the economic use of timber and also conserve the primary species of timber, use of secondary species of timber has been resorted to by giving appropriate seasoning and chemical treatment before use. However, time has come to look for alternatives to timber. The use of steel shaped frames as well as pre-cast concrete and magnesium oxychloride cement door and window frames is becoming increasingly popular.

Pre-cast concrete door/window frames are competitive in cost and function and do not need repetitive maintenance. The latest contribution is the use of ferro-cement. Use of pre-cast hollow decorative blocks has also become very popular mainly through the work of building centers as well as private sector entrepreneurs. With regard to door shutters, the use of alternatives like cement bonded particle boards and bamboo boards are becoming popular in many regions.

### 3.2.7 Inter-locking Blocks

The construction industry is acknowledging the strong need to accelerate the masonry construction process, as the conventional method is labor intensive, hence, slower due to the presence of a large number of mortar joints. There is need for further acceleration of the rate of construction leading to the elimination of bedding mortar and thereby to the development non-conventional methods of masonry construction techniques, one that adopted special interlocking blocks as well as conventional blocks.
With the use of conventional blocks, adoption of partial grouting and surface bonding becomes essential. Interlocking blocks further differ from conventional blocks in that the units are assembled together using geometrical features incorporated in the units without the aid of mortar. Attempts have been made to increase productivity through the development of varied types of interlocking blocks.




Advantages of Interlocking Blocks/Bricks

Deductions from a laboratory study on masonry works carried out reveals the following conclusions applicable to the methodology adopted and the range of parameters investigated:

1 Interlocking blocks masonry has much higher output per productive hour compared to conventional – brick/hollow – block masonry
2 Due to easier alignment facilitated by the interlocking features and the elimination of vertical joints, a production enhancement of 80 - 120% and 60 – 90% more than conventional masonry was observed for dry-stacked masonry and thin-jointed, mortar bedded interlocking-block masonry respectively. Compared to conventional masonry, the interlocking-block has less indirect contributory work- the reduction ranging from 30 -50%.

### 3.2.8 Concrete Block

The three methods of concrete block making considered are summarized below.

*Option 1 - Automated mass production*

This is a capital intensive manufacture, low labor option, based on modern high speed concrete block manufacturing equipment. Being one of the smallest commercially available automated plants; it represents the option requiring the least capital input of the truly automated plants. It requires a reliable electricity supply, access to gas or oil supplies.

*Option 2 - Mechanically assisted manual production*

This is labor intensive multiple-unit manufacture assisted by "low technology-low capital investment" equipment which has been designed to reduce the manufacturing costs. This option requires minimum capital input. It does not require an electricity supply or access to gas or oil supplies.

*Option 3 - Manual single concrete block mould*

This is labor intensive manufacture, based on manually mixing bagged cement and locally quarried sand and aggregate. Typically the mix will be prepared in a tub and poured into a steel or aluminum mould, perhaps several at a time, and allowed to cure overnight before being stripped from the mould.

### 3.2.9 Bamboo (Vegetable Steel)

For housing radical new ideas are needed. For example, one of the best structural materials available in abundance is bamboo. There are many advantages to using bamboo in construction. It is a highly functional, beautiful, earthquake-indifferent material. Bamboo occurs in many sizes, many degrees of hardness, and many grades of color and occupies a wide range of habitats. It is possible to build multiple-storey buildings with bamboo. Whereas trees must be replanted when they are harvested, bamboo roots sprout up again quickly

In the modern context when forest cover is fast depleting and availability of wood is increasingly

becoming scarce, the research and development undertaken in past few decades have established and amply demonstrated that bamboo could be a viable substitute of wood and several other traditional materials for housing and building construction sector and several infrastructure works. Its use through industrial processing have shown a high potential for production of composite materials and components which are cost-effective and can be successfully utilized for structural and non-structural applications in construction of housing and buildings. Main characteristic features, which make bamboo as a potential building material, are its high tensile strength and very good weight to strength ratio. It can withstand up to 3656 $Kg/cm^2$ of pressure.
It can be easily worked upon by simple tools and machines. The strength-weight ratio of bamboo also supports its use as a highly resilient material against forces created by high velocity winds and earthquakes. Above all bamboo is renewable raw material resource from agro-forestry and if properly treated and industrially processed, components made by bamboo can have a reasonable life of 30 to 40 years. Though, natural durability of bamboo varies according to species and the types of treatments. Varied uses and applications in building construction have established bamboo as an environment-friendly, energy-efficient and cost-effective construction material. With the rising need of housing, buildings and roads the country requires a variety of alternate building materials and construction systems and advancements in bamboo technology offer several cost effective and environment friendly options.

Bamboo as a versatile material and its various composites along with other building materials offer a very appropriate option to partially replace materials like steel, aluminum and hard forest wood for housing applications. Uses of bamboo in buildings:

- Door shutters
- Flooring
- Shuttering and Scaffolding
- Roofing sheets

### 3.2.10 Other Elements

The scope for the use of pre-cast elements is coming into sharp focus for areas of application such as:

- Thin pre-cast lintels
- Thin ferro-cement pre-cast shelves
- Pre-cast sanitation unit rings
- Pre-cast septic tanks

- Ferro-cement bio-gas units
- Pre-cast jalousies
- Pre-cast poles for street lighting
- Pre-cast posts for boundary walls
- Ferro-cement based sanitation units/cladding
- Ferro-cement water tanks
- Pre-cast well rings for water wells

The use of ferro-cement water tank has become very popular. Similarly, the use of pre-cast well rings for water well has also caught up because of their popularity and the fact that they are manufactured by private sector outlets as well as through the building centers. The sanitation schemes using twin pits is also giving rise to the manufacture of the rings for sanitation. Pre-cast poles for the street lighting have become increasingly popular for the land development as well as electricity boards due to scarcity of timber poles and also the exorbitant cost of the same. Even metallic telephone poles can be replaced with pre-cast concrete poles.

## 3.3. Prefabrication

Pre-cast concrete door and window frames have been developed which are economical compared to timber frames besides being resistant to decay and ant attack. Several low cost pre-cast roofing units such as doubly curved tiles, pre-cast cellular units, cored concrete, etc., have been developed and successfully used in buildings.

Here it will be tried to point out the various aspects of prefabricated building methodologies for low cost housing by highlighting the different prefabrication techniques, and the economical advantages achieved by its adoption. In a building the foundation, walls, doors and windows, floors and roofs are the most important components, which can be analyzed individually based on the needs thus, improving the speed of construction and reducing the construction cost.

The concept of pre-cast (also known as "prefabricated") construction includes those buildings where the majority of structural components are standardized and produced in plants in a location away from the building, and then transported to the site for assembly. These components are manufactured by industrial methods based on mass production in order to build a large number of buildings in a short time at low cost. The main features of this construction process are as follows:

- ❖ The division and specialization of the human workforce
- ❖ The use of tools, machinery, and other equipment, usually automated, in the production of standard, interchangeable parts and products.

This type of construction requires a restructuring of the entire conventional construction process to enable interaction between the design phase and production planning in order to improve and speed up the construction. One of the key premises for achieving that objective is to design buildings with a regular configuration in plan and elevation.

Many countries used various pre-cast building systems during the second half of the 20th century to provide low-income housing for the growing urban population. In general, pre-cast building systems are more economical when compared to conventional multifamily residential construction (apartment buildings) in many countries.

Depending on the load-bearing structure, pre-cast systems can be divided into the following categories:

- Large-panel systems
- Frame systems
- Slab-column systems with walls
- Mixed systems

### 3.3.1 Large-Panel Systems

The designation "large-panel system" refers to multistory structures composed of large wall and floor concrete panels connected in the vertical and horizontal directions so that the wall panels enclose appropriate spaces for the rooms within a building. These panels form a box-like structure (see Figure 3). Both vertical and horizontal panels resist gravity load. Wall panels are usually one story high. Horizontal floor and roof panels span either as one-way or two-way slabs. When properly joined together, these horizontal elements act as diaphragms that transfer the lateral loads to the walls.

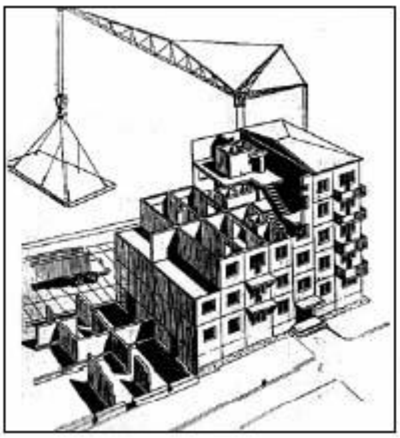


Figure 3: A large-panel concrete building under construction (WHE Report 55, Russian Federation)

### 3.3.2 Frame Systems

Pre-cast frames can be constructed using either linear elements or spatial beam-column sub-assemblages. Precast beam-column sub-assemblages have the advantage that the connecting faces between the sub-assemblages can be placed away from the critical frame regions; however, linear elements are generally preferred because of the difficulties associated with forming, handling, and erecting spatial elements. The use of linear elements generally means placing the connecting faces at the beam-column junctions. The beams can be seated on corbels at the columns, for ease of construction.

The beam-column joints accomplished in this way are hinged. However, rigid beam-column connections are used in some cases, when the continuity of longitudinal reinforcement through the beam-column joint needs to be ensured. The components of a pre-cast reinforced concrete frame are shown in Figure 7.

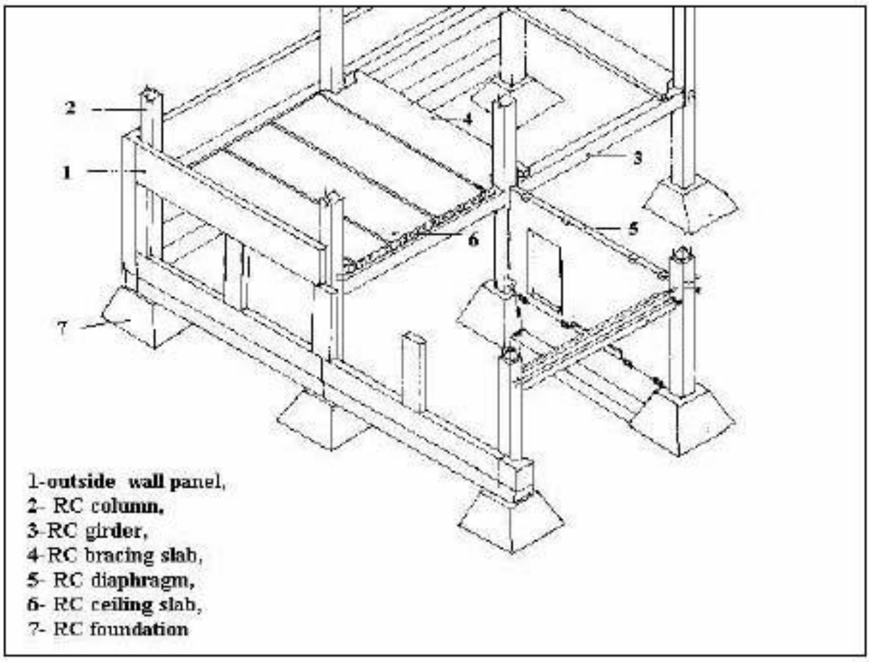



Figure 7: Components of a precast reinforced concrete frame system of Seria IIS-04 (WHE Report 66, Uzbekistan)

### 3.3.3 Slab-Column Systems with Shear Walls

These systems rely on shear walls to sustain lateral load effects, whereas the slab-column structure resists

Mainly gravity loads. There are two main systems in this category:

- Lift-slab system with walls
- Pre-stressed slab-column system

The load-bearing structure consists of pre-cast reinforced concrete columns and slab. Pre-cast columns are usually two stories high. All pre-cast structural elements are assembled by means of special joints. Reinforced concrete slabs are poured on the ground in forms, one on top of the other. Pre-cast concrete floor slabs are lifted from the ground up to the final height by lifting cranes. The slab panels are lifted to the top of the column and then moved downwards to the final position. Temporary supports are used to keep the slabs in the position until the connection with the columns has been achieved.

## 3.4. Standardization and Mechanization

In high-income countries, building products manufactured locally by automated processes can be distributed cheaper than their manually manufactured competitors. In low-income and middle-income countries, building products manufactured locally by automated processes can be distributed cheaper than their manually manufactured competitors only if the market is predictable and sufficiently large enough to provide a reasonable return on the capital invested. Otherwise, manually produced products will hold a competitive edge.

In low-income and middle-income countries, building products manufactured locally by mechanically assisted manual methods may provide a cheap building products, a reasonable level of local employment and a reasonable return on a relatively low level of investment. In the short term, manual production and mechanically assisted manual production provide more opportunities for local employment than automated production. There are two direct approaches towards cost reduction in brick production, viz. mechanization of the brick making process and improvement of the efficiency of brick kilns.

## 3.5. Summary

Most countries have locally garnered traditional materials, usually based on earth and plants. Materials such as stone, clay for bricks and tiles, earth in various guises, lime, timber, bamboo, sisal and grass all feature in traditional housing. Even animal products such as skins, shells and dung are used in some societies. Most are regarded as unfit for urban use through building regulations introduced in the 1930s, often based on Portland cement, and little altered since. However, many very serviceable materials were given a bad name without reason. Now, there use is confined to informal areas, outside building and planning controls, and regarded by policy-makers and members of élites as undesirable. RCC is almost mythical in its power. Post and slab, cantilevering, and all the other tricks seems to allow almost anything to be done in housing. However, for most housing purposes, the full strength of concrete is unnecessary. Local earth- and timber-based materials can be more appropriate and much more affordable.

| | **Total no. of houses** | **Area of flooring available (lakh sq. ft.)** | **Assuming 10% of flooring to be replaced by bamboo flooring (lakh sq. ft.)** | **Cost of bamboo flooring per sq. ft. (Rs.)** | **Cost of flooring using bamboo (Rs. In lakhs)** |
|---|---|---|---|---|---|
| Urban | 11 lakh | 3520 | 352 | 50 | 17600 |
| Rural | 25 lakh | 2550 | 255 | 50 | 12750 |
| Total | 36 lakh | 6070 | 607 | | 30350 |

# Chapter 4
# Labor

## 4.1. Low cost labor intensive technologies

Work force in construction project would include *professional, skilled, semi skilled and unskilled laborers*. Target: to do jobs in a lesser time (lesser direct cost) => lesser construction cost => building with a lesser cost

Low-income housing developments in the formal sector tend to be in the middle range of benefit for development, and high-income housing is the least favorable. A study in Mexico suggests that the cheaper the conventional housing, the greater is the proportion of total construction cost that goes to labor. A more elaborate study of low-income housing in Kenya also confirms that less expensive forms of housing generate more employment. Therefore, self-help or low-income housing which tends to be built by the informal sector with its greater labor-intensity, use of indigenous techniques, unskilled labor, and small firms should be encouraged. The informal sector is particularly efficient in this because its construction is simpler than in the formal sector and appears to consume less labor per unit cost. Investment of a given amount in informal housing tends to generate about one in five more jobs than in formal housing besides contributing six times as many (lower standard) dwelling units.

Building low-cost housing can be very beneficial in employment and income for the local area. If materials are won or made locally, the direct employment can be augmented by local jobs in materials industries. Also, the profits and income multipliers from local industries benefit the local people.

Cement tends to be made in large plants so the economic benefits are rarely close to the building site. Large cement plants have little employment potential per unit of production. By contrast, making bricks in small local production units can provide 77 per cent of their value in employment. They generate about 50 times as many jobs as the large cement works and five times as many jobs as medium-scale cement products manufacture. Cement blocks can be made in labor-intensive methods, close to the site. This creates work to about 20 per cent of the value of the products, but quality issues may become insuperable.

Aggregates production can be labor intensive but usually is not. Where it is, such rock breaking work is very strenuous and unfulfilling. For example, the women who break bricks for aggregate on Bangladeshi streets cut a very sorry figure. Local manufacturing of selected building products and the resulting increase in employment can be encouraged by local housing projects.

Most conventional methods require a variety of skill levels to undertake even the simplest of structures. In a recent survey of brick/block yards, lack of training (skills) was identified as a major weakness in the industry. Thus any new or proposed techniques must aim at either provision of training as part of the package or must have a relatively low requirement for specialized skills. However, techniques such as the use of pre-cast concrete panels as building elements have shown a tremendous reduction in specialized skills requirements.

Techniques towards efficient manpower management:

- Avoid variability of items of works (Repetitiveness)
- Use of readily/locally available workforce
- One approach, engineering wise, to developing a viable solution is to focus on building modules that are lightweight, simple to assemble, and require minimum skilled labor.
- The use of unskilled and the unemployed: There is often an abundance of unemployed building workers in informal settlements; building workers with the lowest levels of building skills. Skilled building artisans are in short supply throughout the world. However, building technology has also in some respects advanced beyond traditional building techniques so that a high level of training is not always necessary. Some of this does not need heavy manual labor so that the erection of housing no longer needs to be gender specific. Whatever extra skills are needed can be obtained while building.
- Manuals and guidelines

## 4.2. Modular and requiring less skill

***Refer to the discussion in Chapter 5***

# Chapter 5
# Wastage

Waste can be defined as any losses produced by activities that generate direct or indirect costs but do not add any value to the product from the point of view of the client.

Objective: Minimize wastage (minimize labor and material cost indirectly) => minimize expense => cost effective building

Techniques:

- ✓ Modular building materials
- ✓ Pre-cast concrete
- ✓ Building materials with various shapes and geometry
- ✓ Dimensioning spaces taking into account the available standard building materials and the overall building project

Example:

– HCB – with outer dimension 32x19x16 cm (w x h x d)
– Three types of measurements to calculate height dimensions

• **Full Size:**

Plan measurements = (32 cm + 1 cm) x n -1 cm

Elevations and sections = (19 cm + 1 cm) x n

Note

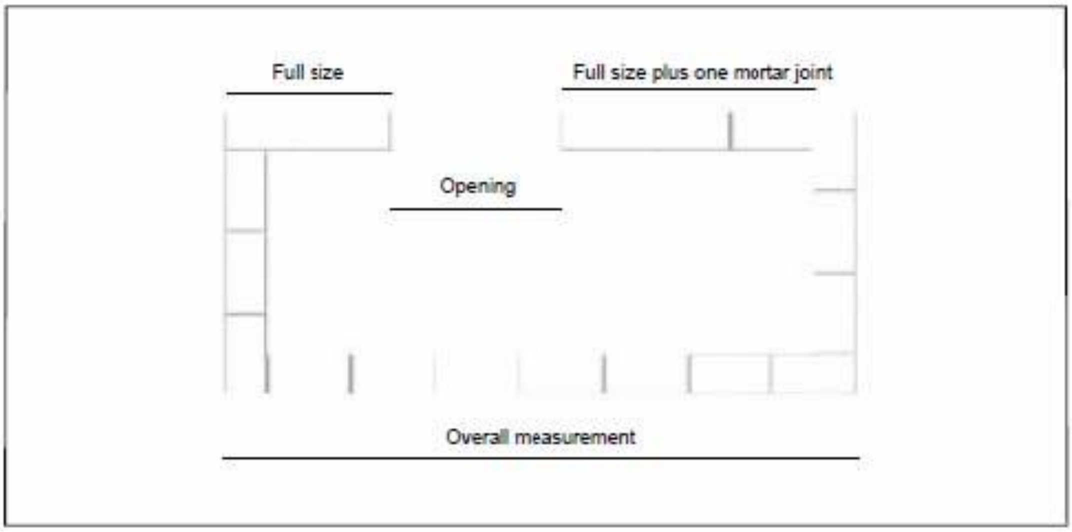
n = units used
Mortar joint = 1cm

• **Full Size plus one mortar joint:**

Length = the unit size plus one mortar joint multiplied with the number units used (n).

• **Openings:**

Opening size = the module size plus one mortar joint multiplied with the number of units used (n) plus one additional mortar joint.

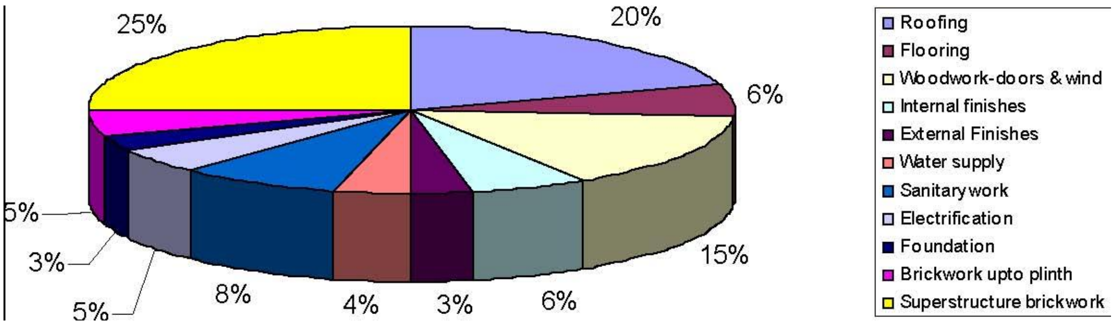

Full size
Full size plus one mortar joint
Opening
Overall measurement

# Chapter 6

## Building Systems

There are technologies which are proven to be appropriate and viable in the context of low-income housing delivery and a vast majority of population is using them in many regions of some developing countries like India. A brief description of some of these technologies follows.

**Approximate Break-up of Total Construction Cost for Different Elements of Building**




### Ground Investigation and Foundation Systems

Special mention may be made of deep subsoil exploration and sampling by use of bentonite slurry. The process is simple and fast and the equipment required is inexpensive. The method avoids use of casing pipes and is speedy. For obtaining undisturbed soil samples a simple device can be used which ensures continuous penetration. The sampler opens by rotating the drill rod only at the desired depth. It has been successfully used for recovering undisturbed soil samples from depths up to 80 meters from sandy river bed at a bridge site.

The technique of under-reamed pile foundations developed in India has proven to be both economical and efficient. A similar technology has been exercised in Ethiopia in CCD real estate project. These are short bored concrete piles having a large bulb at the bottom. More than 20,000 buildings have been constructed up-to-date on such foundations and an economy of 25 to 40 per cent in the foundation cost has been reported. The scope of under-reamed piles has been extended to sandy soils and filled up grounds. For heavier loads the use of multi-under-reamed piles has been advocated.

**Building Services**

Affordable housing must incorporate effective means of waste removal and reliable clean water supply. The normal drainage system for a house as per existing practice involves the use of two main waste pipes, the soil stack taking the discharge from the W. C. and another pipe taking the waste from the bath and the wash basins.

In this system, vent pipes are fitted to prevent the unsealing of the traps of various appliances. It has been shown that these vent pipes are often unnecessary and a single stack system where all appliances inclusive of W.C. discharge into one stack and the traps are unventilated, can be safely used. This single stack system has been successfully tried in several multi-storeyed buildings. Improved ''Dual acting'' flushing systems have been developed for the conservation of water which is a problem in big cities.

**Bonding System**

A very innovative area where cost reduction can be achieved is in the use of economical and innovative bonding systems using, for example, "rat trap bond" as against "English and/or Flemish bond". Over 25 per cent saving in bricks and mortar is achieved with proven structural strength and better thermal efficiency. The technology has not only proved to be useful and economical but also has resulted in aesthetical housing options.

*Rat-trap bond in wall construction:* While laying bricks, the manner in which they overlap is called the bond. There are several types of bonds developed in different countries from time to time.

The rat-trap bond is laid by placing the bricks on their sides having a cavity of 4″ (100 mm), with alternate course of stretchers and headers. The headers and stretchers are staggered in subsequent layers to give more strength to the walls. The main advantage of this bond is the economy in use of bricks, giving a wall of one brick thickness with fewer bricks than a solid bond.

- Strength is equal to the standard 10″ (250 mm) brick wall, but consumes 20% less bricks.
- The overall saving on cost of materials used for construction compared to the traditional 10″ (25cm) wall is about 26%.
- The air medium created between the brick layers helps in maintaining a good thermal comfort inside the building. This phenomenon is particularly helpful for the tropical climate.
- As construction is done by aligning the bricks from both sides with the plain surface facing outwards, plastering is not necessary except in a few places. The finished surface is appealing to the eye.
- Buildings up to two stories can easily be constructed with this technique.

❖ In RCC framed structures, the filler walls can be made of rat-trap bond.

*Brick arches:* The traditional RCC lintels which are costly can be replaced by brick arches for small spans and save construction cost up to 30–40% over the traditional method of construction. By adopting arches of different shapes blended with brick corbelling, a good architecturally pleasing appearance can be given to the external wall surfaces of the brick masonry.

*Filler slab in roof:* This is a normal RCC slab where the bottom half (tension) concrete portions are replaced by filler materials such as bricks, tiles, cellular concrete blocks, etc. These filler materials are so placed as not to compromise the structural strength, result in replacing unwanted and non-functional tension concrete, thus resulting in economy. These are safe, sound and provide aesthetically pleasing pattern ceilings and also need no plaster.

The main features of the filler slab are:

- Consumes less concrete and steel due to reduced weight of slab by the introduction of a less heavy, low-cost filler material like two layers of burnt clay tiles.
- Slab thickness is minimum (112.5 mm).
- Enhances thermal comfort inside the building due to heat-resistant qualities of filler materials and the gap between two burnt clay tiles.
- Makes saving on cost of this slab compared to the traditional slab by about 23%.
- Reduces use of concrete and saves cement and steel by about 40%.

*Compressed earth block*

Compressed earth blocks (CEBs) are earthen bricks compressed with hand-operated or motorized hydraulic machines. Stabilizers such as cement, gypsum, lime, bitumen, etc. are used during production or on the surface of the bricks. In many areas of the world, proper materials are available for making CEBs, and thus this type of block may be a better choice than any other building material.

One of the factors that affect the use of CEBs is the mental barrier of using simple earth rather than burnt clay bricks. Non-availability of skilled manpower and technical guidance to produce large quantities of CEB with proper quality is also a determinant force.

Advantages of CEB include:

- Uniform building component sizes, which result in faster construction.
- Use of locally available materials and reduction of transportation (CEBs are mostly

produced locally by transporting the equipment and machine at the work site).

- Modular elements like sheet-metal roofing, and pre-cast concrete door/window frames can be easily integrated into a CEB structure.
- The use of locally available materials and manpower helps in improving local economy rather than
spending for procuring building materials from a distant place.
- The earth used is generally subsoil and thus the top agricultural soil remains intact.
- The reduction of transportation requirement can also make CEB more environment-friendly than other materials.
- $CO_2$ emission is practically nil in the production of CEBs.
- If the wet compressive strength is more than 20 kg per sq. cm, then a RCC roof can be laid and a second storey can be built. If the blocks have more than 8% cement stabilization, then a three-storey, load bearing structure can be built. But, in such cases, expert advice is suggested.
- Good quality blocks having lesser water absorption can safely be used in areas with high rainfall.

**Construction Systems**

Two Basic Construction Systems are:

❖ Industrialized systems

- Based on factory produced components (partial/total)
- Less labor intensive
- High performance specifications

❖ Alternative systems

- Middle of the road approach
- Acknowledges local materials and skills
  - Rationalizes use of suit specific needs
  - Adopts rational engineering practices
  - Cost effective and eco-friendly

Various aspects for alternative systems

- Optimization of land use
- Functional design of buildings
- Optimum use of building materials
- Rationalization of specifications
- New construction materials and techniques

**Alternative Housing Systems**

Aims to reduce the cost of construction and at the same time not sacrifice any element of safety or serviceability of the house over the life cycle.

There is need for adoption of:

- strong,
- durable,
- functional,
- aesthetic,
- environmental friendly,
- ecologically appropriate,
- energy efficient,
- affordable and adaptable,
- cost-efficient materials and appropriate technologies in construction.

Alternative Systems

- Foundations
- Walls
- Roofs/slabs and door frames and panels

Emerging Technologies

- Rapid wall systems
- Monolithic Concrete Construction Technologies
- Mortar less Masonry (Interlocking)
- Confined Masonry
- Light Weight Construction Technology
- Technologies based on Agro-Industrial Waste
- Bamboo Based Technologies
- Pre-Engineered form work systems
- Fiber Cement Board, Expanded Polystyrene (EPS) blocks and concrete
- Fiber cement board, expanded polystyrene (EPS) blocks, light gauge steel studs & concrete
- Light weight interlocking sandwich panels Facing sheets: 4mm thick Fiber Reinforced Cement boards.

Core: Aerated Cement, Silaceous & Micaceous Material aggregate and 3-S Prefab systems with hollow structural components connected using SCC.

# Chapter 7

## Conclusion and Recommendations

Despite considerable progress has been achieved in developing countries in the past two decades in policy formulation, facilitating a shift of the public sector's role to strengthening of enabling strategies and focusing on the utilization of the potential and capacity of informal sectors, there is a widening gap between policy formulation and the implementation process, and the status of low-income housing delivery is far beyond being satisfactory.

There are many constraints for this situation. Lack of effective implementation strategies, poor promotion of security of tenure, inadequate supply of affordable land and infrastructure, inadequacy of housing finance systems, *poor utilization of local building materials and technologies*, lack of support to small-scale construction activities, inappropriate standards and legislation, inadequate participation of communities in shelter development process and support to self-help, lack of focused research and experimental projects, poor utilization of research findings, are amongst such major constraints.

When introducing a new appropriate low-cost housing design it is important that it is not deemed as a type of houses only for low-income families. Social impact and effect of status is in this case very important. People with a low income do not want to live in houses labeled only for low-income people, because then everybody knows that the persons living in these houses are poor. The standardization of technology is imperative to such communities to manage perceptions. Lower income groups tend to copy the houses of the rich, which also is one of the reasons why it is important that adoption of sustainable technologies must be implemented at all levels.

The ever increasing building cost in the developing world is a matter of serious concern that calls for the appraisal of the conventional building processes in seeking for alternative building materials and methods. Currently, the cost of materials and labor is continually on the increase beyond the reach of many citizens. It is observed that the rising cost of buildings can be attributed to a number of factors, which include high transportation cost, devaluation of national currency, inability of production companies to meet high demand for building materials, uncontrollable prices of building materials and particularly, the over-dependency on imported building materials that is constantly subject to inflation.

There are a variety of factors, which affect building costs, and unless these are concurrently dealt with, substantial saving can not materialize. For example, using low-cost blocks with wasteful use of land and high construction overheads may ultimately prove expensive. Often low-cost is identified with low performance. It is important that in spite of the low cost, the performance should conform to the requirements of building codes. Besides, the evaluation should be on the basis of the performance required from a particular structure and on the individual's needs. In recent years the cost of labor has increased concurrently with the increase in the cost of building materials. Therefore, any building method which reduces the use of material, especially cement, steel and bricks, and cut down the on labor, will result in overall saving. The following steps may be taken to ensure proper and extensive use of CET in the light of sustainable development and protection of the environment:

- ***Sensitization of people:*** Extensive awareness campaigns and demonstrations among general public and also among engineers and architects to make them familiar with these technologies. The market force of cost reduction will definitely play a major role in acceptance of CET if Governments/Municipal Bodies acknowledge these technologies and direct their concerned departments to adopt them. Promotion of cost-effective technologies through institutes may also be thought of.

- ***Manpower development:*** To promote cost-effective technologies, skills up gradation programs have to be organized for construction workers. These technologies should also be a part of the syllabus for students of civil engineering and architecture at undergraduate and diploma level.

- ***Material development:*** Federal and State Governments should encourage the setting up of centers at regional, rural and district levels for production of cost-effective building materials at the local level. Appropriate field level research and land-to-lab methodology should be adopted by leading R&D institutes and universities to derive substitutes to common energy-intensive materials and technologies. Reuse of harmless industrial waste should also be given priority.

- ***Technical guidance:*** Proper guidance to general public through design, estimation and supervision has to be provided by setting up housing guidance centers, in line with the concept mooted by building research centers and relevant educational institutes.

**Table 5 Reduction in $CO_2$ emission for a 50 sq. m building**

| Building material required by conventional method | Reduction by using cost-effective construction technology (rat-trap bond wall, brick arch and filler slab) | Reduction in carbon dioxide emission (kg) |
|---|---|---|
| Brick – 20,000 nos | 20% | 1440 |
| Cement – 60 bags or 3.0t | 20% | 540 |
| Steel – 500 Kg or 0.5t | 25% | 375 |
| Total reduction in carbon dioxide emission | | 2355 (2.4t) |

**Table 6 Comparative Cost Economics**

| **Item** | **Conventional** | **Cost Effective** | **Savings** |
|---|---|---|---|
| Foundation | Dead Load - 101.5KN/m | Dead Load - 81.3KN/m | 20% |
| Walls | English Bond Brick Wall - 1450/$m^3$ | Rat-trap Bond Brick Wall -1150/$m^3$ | 20% |
| Roofing | Cast in-situ RCC 578/$m^3$ + 37/$m^3$ (plastering) | Pre-cast RCC 456/$m^3$ | 21%<br>6% |
| Door & Window Frames | Wooden Frame 135/RM MS Tee frame | Pre-cast RC Frames 100/RM | 35% |
| Door Shutters | Wooden Shutter - 1200/RM | F:R:P. Doors 950/RM | 20% |
| Staircase, Sunshades, Lintels | RCC Cast in-situ 560/RM | Pre-cast Ferro cement 450/RM | 25% |

**Table 7 Summary of cost reduction through different approaches**

| | Cost-Effective Technologies | In place of conventional options | % of saving |
|---|---|---|---|
| **I. Foundations** | | | |
| 1. | Pile foundation (under reamed) | Traditional stone/bricks | 15 |
| 2. | Brick Arch foundations | Footings | 25 |
| **II. Walling (Super Structure)** | | | |
| 1. | 230mm thick wall in lower floors | 330 mm brick walls | 5 |
| 2. | 180mm thick wall in bricks | 230mm brick walls | 13 |
| 3. | 115mm thick recessed walls | 230mm brick walls | 20 |
| 4. | 150/200mm stone block masonry | Random block masonry | 30 |
| 5. | Stabilized mud blocks | Burnt brick walls | 20 |
| 6. | FaL-G Block Masonry | Clay brick walls | 20 |
| 7. | Fly ash block walls | Clay brick walls | 25 |
| 8. | Rat trap bond walls | English/Flemish bond | 25 |
| 9. | Hollow block walls | Solid Masonry | 20 |
| **III. Roofing** | | | |
| 1. | 85mm thick sloping RCC | 110 mm RCC | 30 |
| 2. | Tiles over RCC rafters | Tiles over timber rafters | 25 |
| 3. | Brick panel with joists | RCC | 20-25 |
| 4. | Cuddpath slabs over RCC rafters | CS over timber rafters | 20 |
| 5. | L-panel sloping roofing | RCC | 10 |
| 6. | RCC planks over RCC joists | RCC | 10 |
| 7. | Ferro cement shell roofing | RCC | 40 |
| 8. | Filler slab roofing | RCC | 22 |
| 9. | Waffle roofing | RCC | 15 |
| 10. | RCC channel units | RCC | 12 |
| 11. | Jack arch brick roofing | RCC | 15 |
| 12. | Funicular shell roofing | RCC | 18 |
| 13. | Brick funicular shell roofing | RCC | 30 |
| 14. | Precast blocks over inverted T-beams | RCC | 25 |
| 15. | Micro-concrete roofing tiles | Clay tile roofing AC sheet roofing | 20 15 |

**Table 7 Summary of cost reduction through different approaches (Cont…)**

| **IV. Miscellaneous Items** | | | |
|---|---|---|---|
| **Cost-Effective Technologies** | | **In place of conventional options** | **% of saving** |
| 1. | RCC door frames | Timber Frames | 30 |
| 2. | Frameless doors (only insects) | Frames and shutters | 50 |
| 3. | Ferro cement door shutters | Timber shutters (second class timber) | 30 |
| 4. | RCC window frames | Timber frames | 30 |
| 5. | RCC jailers | Timber Windows/ventilators | 50 |
| 6. | Pre-cast thin lintels | RCC lintels | 25 |
| 7. | Pre-cast sunshades | Cast in-situ sunshades | 30 |
| 8. | Ferro cement sunshades-cum-lintel | RCC lintel-cum-sunshades | 50 |
| 9. | Brick on edge lintels | RCC lintels | 50 |
| 10. | Corbelling for lintels | RCC lintels | 40 |
| 11. | Brick arch for lintels | RCC lintels | 30 |
| 12. | Pre-cast RCC shelve units | Timber/concrete | 20-35 |
| 13. | Pre-cast ferro cement Shelves | Timber/concrete | 35-45 |
| 14. | Ferro cement manhole covers | Caisson/concrete | 50-40 |
| 15. | Ferro cement water tank | Rigid PVC | 60 |