Manufacturing Framework and Cost optimization for Building Mud Concrete Blocks

C. Udawattha, R. Arooz and R. Halwatura

Department of Civil Engineering, Faculty of Engineering, University of Moratuwa; udawatthe@gmail.com, rizznaz@gmail.com, rangikauh@gmail.com

Abstract

Mud concrete block (MCB) is a novel product which employs a 'Concrete' made from soil. In the composition of MCB, sand and metal of concrete are replaced by fine and coarse aggregates of soil. The precise gravel and sand combination governs the strength of the MCB. Cement in very low quantities is also used as a stabilizer in this concrete. This paper concerns the mix properties, manufacturing framework and cost optimization of MCB developed by the University of Moratuwa. The proposed mix was tested with different cement percentages to optimize it to suit the required wet and dry strength of the block. However, introduction to industry is necessary in to commercialize this novel product. In order to optimize the cost of the product "process optimization" was used. The mould was optimized using a series of calculations and 3D design software to maximize the use of steel or wood with less wastage. The labour input into a number of moulds was optimized by using linear optimization techniques. Linear optimization showed that the number of blocks that can be made of one steel sheet is twenty-eight and the best method is to build two moulds out of two sheets and that the best labour combination for manufacturing MCB is the use of three labourers for two mould combination doing two cycles per day. Then total per day block output would then be one hundred and twelve blocks

Introduction

Sri Lanka is a developing country located in the centre of Indian Ocean. Most of the construction technologies used by Sri Lankans are imposed and unsustainable.[1] Further, the method of building construction has not changed over centuries.[2] In order to change the mode of building construction, the country needs to encourage new research and development to face the challenges in a new era.

Introducing 'Mud concrete block' (MCB) is one such novel research which has been developed by University of Moratuwa. The novel concept in MCB is that employs a 'Concrete' made using earth/soil. Concrete is a typical composite material made of cement, sand, metal and water. In Mud-Concrete, sand and metal of concrete are replaced by fine and coarse aggregates of soil. The precise gravel percentage governs the strength of Mud-Concrete. [3] Cement is also used as a stabilizer in very low quantities in this concrete.[4]

In any production line or a process, economies of scale are the cost rewards that one endeavours to obtain by changing size, output, or scale up of the manufacturing process to influence the cost per unit output scenario.[5] The increase of cost does not always affect the line of production.[6] The simple method of calculating the line of production is through economies of production. The scale can be defined by a simulation series of combinations of production. The operation cost is always an easy variable while capital cost is a hard variable.[7] Theoretically, the production function shows constant returns to scale if increasing all inputs by all mean are not variables. The return of scale can be minimized by the scale of inputs.[8,9].

Methodology

The key objective of this research was to understand the mix properties of MCB and optimize the method of manufacturing mud concrete block. Therefore, the experiment had to be done in a real world scenario where both raw material and manufacturing could be simulated accordingly. The followings approaches were considered in developing strength and durable parameters of MCBs while ensuring indoor comfort, low cost, and easy construction technique.

The first step was to change the fine percentage while keeping sand and gravel constant.

1. Once the optimum/ most practical fine content is known, the sand/gravel percentage was changed to find the optimum sand and gravel contents.
2. The proposed mix was tested with different cement percentages to optimize it to suit the required wet and dry strength of the block.

Finding the mix properties was the turning key of this research to develop the mud concrete block. The second step was to determine a framework for manufacturing MCBs in a mass scale. Therefore, the method of building the mould and the best labour combination were ascertained using a series of real world simulations

Linear Optimization

Linear optimization is a method of simulating scenario base system into experiment models.[10] Optimization problems are omnipresent when experimenting in real-world systems. These types of simulation optimization applications are commonly used in management fields where input and output can be optimized by controlling input. Linear Optimization modeling does not require time as an appropriate factor. The universal routine that can be used in optimization process modeling is to a. draw the problem, b. prescribe a solution, and c. control the problem by changing/updating /revising the optimal situation continuously. The optimum can be excluded by understanding input-output scenario or the efficiency of the process.[11]
Mathematical Formulation of real world problems is not an easy task.[12,13] However, formulating a mathematical solution to obtain a suitable formula can be interesting in order to determine the optimization method.[14]
When one detects a problem and understands it, one can use a mathematical formula or a curve to adequately describe it concisely. Although one can develop a mathematical model or framework to represent reality to devise or use in an optimization solution it must be validated before it is offered as a solution.[15]

Real world simulation model

The scenarios for real world testing was arrived at by the simulation of inputs in the MCB manufacturing process such as a. labour b. number of moulds and c. number of sites. The key objective of the research was to understand the optimum combination of labour and moulds. Cement optimization was done in previous research and it was confirmed that 6% of cement should be added. Therefore, inputs such as raw materials in the MCB were disregarded while calculating optimum combinations for MCBs.
The final cost and the block manufacturing efficiency was measured and analyzed in order to understand the optimum output of the MCB manufacturing process.

Attributes of optimization model

The main attributes of MCB are its manufacturing process inputs. They govern the final cost and the efficiency of the MCB manufacturing process. The amount of labour in man hours govern the speed of output. In some cases, the by increasing labour, one can increase production. However, sometimes increase of labour may decrease the efficacy of output. This is defined as labour depreciation. The number of moulds also defines the total output per session. The number of devices can determine the number of blocks manufactured at a single time. Therefore, the number of moulds directly governs the efficiency of MCB production. The number of sites is a variable factor whereas the number of sites per single mould can define the total cost of a block in terms of mould cost.

Finding Mix Properties of MCB

Impact of fine/soil particle content

A set of experiments was conducted varying the content of fine particles to find out its effect on strength. It revealed that when the fine content was increased, the strength of the product was reduced. Hence, reducing the fine content to as much as possible could achieve a higher strength.

Impact of gravel/sand content

The next step was to find out the effect of gravel/ sand content on the strength of mud concrete. A set of experiments was carried out keeping the fine content constant at 10%. These experiments suggested that mud-concrete had a higher strength when gravel percentage was at a range of 30% - 35%, implying that the optimum sand content to be used in mud-concrete was 55% - 60%.

Effect of Water Content on Strength

One of the unique features of this product was its self-compacting nature. To achieve this quality, water content had to be kept at a higher level. The possibility of defining optimum water content was investigated for the above-mentioned mix.
The strength reduced with higher moisture content. Therefore, it was necessary to keep the moisture content at a minimum level while not disturbing the self-compacting nature. Experiments suggested that a water content of 18% - 20% was required to satisfy these dual requirements.

Optimization Mould for MCB manufacturing

The mould to be used is a the key decision while programming for optimum combinations for manufacturing MCBs. The main series of decision can be made according to a flow chart. Fig. 2 explains how the mould was optimized by considering the property of materials to determine the most the efficient combination of making a number of blocks from one mould. The number of blocks per single mould and the number of blocks from a single sheet was simulated using optimization model changing number of moulds and sheets in an input-output scenario. The material, of course, was decided by considering the available technology (Table 1). A general survey was conducted in order to understand the capability of each and every material in the market and their pros and cons were analyzed accordingly.

Table 5: Optimizing block mould material

Mould material	Pros	Cons
Wood	1. Flexibility 2. Availability 3. Low cost	1. Low Durability 2. Heavy in weight 3. Requires more machinery
Steel	1. Durability 2. Low cost 3. Availability	1. Expensive 2. Need precision work
Fiber Glass	1. Mouldable into many shapes	1. Hazardous 2. Expensive

Table 6. Optimizing best labour combination

	Practice No.	No. of moulds	No. of Cycles	No of Sites	Nos. labour*	No. of blocks	Cost per block
Scenario 1	One	1	4	1	2	2500	Rs.21.95
	Two	2	4	1	2	2500	Rs.15.78
	Three	2	1	2	2	5000	Rs.12.58
	Four	2	2	10	3	2500	Rs.10.02
Scenario 2	Five	3	4	1	2	2500	Rs.15.85
	Six	3	1	2	2	2500	Rs.11.05
	Seven	3	1	10	2	2500	Rs. 7.21
Scenario 3	eight	3	1	1	3	2500	Rs. 9.38
	nine	3	4	2	3	2500	Rs. 9.38
	ten	3	1	10	3	2500	Rs. 9.38

* Single labour cannot handle such a production

Steel was finalized as the best material for moulds for manufacturing MCBs in Sri Lanka after analyzing a survey of the construction community. Table 1 explains how the material decision was done according to their pros and cons analysis.

The most efficient method of manufacturing the mould was determined by using 3D software in order to understand how this would look like in the real world and the practicality of it. The optimum was determined by the optimizing number of blocks (block efficacy) and wastage of steel sheet. One mould per one sheet was optimized by considering its ability to build MCBs with the minimum number of sheets. However, the other combinations such as two moulds from one sheet, two moulds from two sheets and three moulds from two sheets were simulated by using an Excel programme developed by the user.

Finalizing was be done by using a sketch-up 3D model and cut-list plus for measuring cutting methodology and wastage of steel sheet. The price per mould was determined considering the available market conditions in the country. However, the mould manufacturing method and the process was carefully designed by considering Sri Lankan labour skills. Sri Lankans do not have much skill in machinery based manufacturing. Therefore, a simple cut and the joining system were used in order to build the mould.

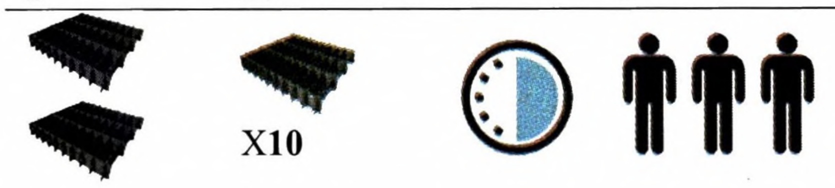
Nevertheless, the final design for MCB manufacturing was tested in the real world scenario by producing a mould in a workshop. The design was changed slightly after understanding the practicality of mould manufacturing as well as the block manufacturing process.

Optimizing Labour composition in manufacturing mud concrete block

Labour is a crucial factor for manufacturing mud concrete block. Thus, the manufacturing process of MCBs may not require skilled Labour. However, labour with first-hand experience would be preferred considering the sensitive process to be undertaken. The labour combination for the manufacturing MCBs was measured and optimized by using the scenario-based method as explained in the methodology section. Linear optimization method was used to understand how the labour, number of moulds and the number of the cycle can be optimized. Table 4. shows how the experiment was done in a real world scenario. All the data was collected by a quantity surveyor and analyzed using an Excel data sheet.**Error! Reference source not found.** also shows that the efficiency can also be increased by employing more moulds and increasing number of man hours, although increasing labour and moulds did not always give better results. However, the optimum combination for manufacturing MCB is seen to be scenario one practice number four (Table 2)..

Table 7. Optimizing block mould material

No. of Moulds	No. of sites per Mould	No. of Cycles per day	No.of Labour
2	10	2	3



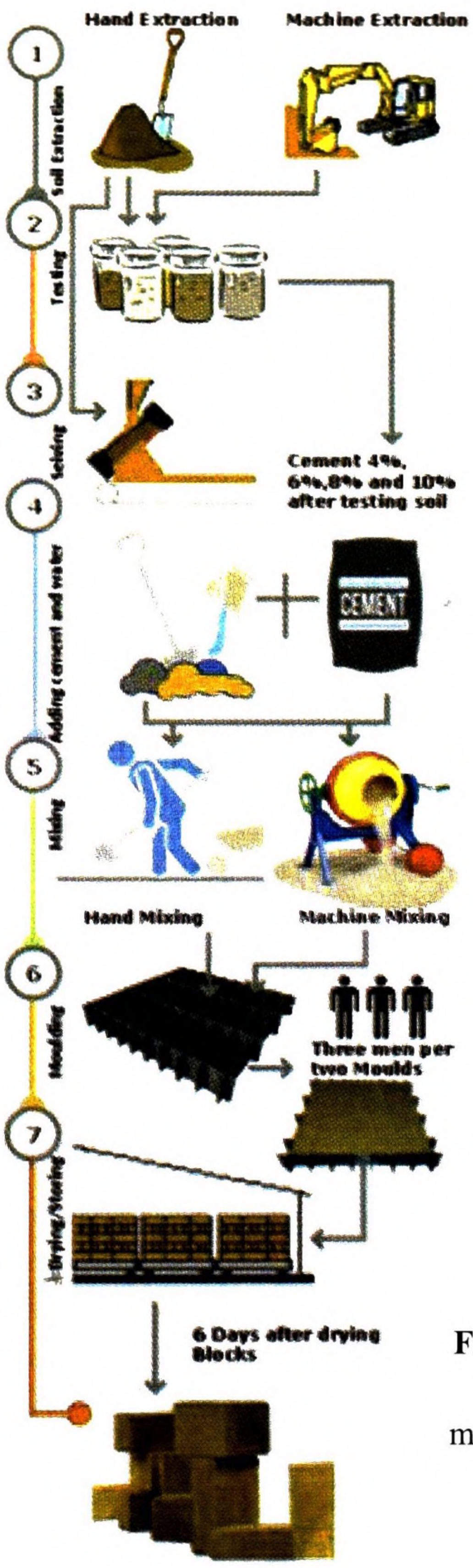


Fig. 1. Seven stages in manufacturing MCBs

Table 4. Optimizing best labour combinations (Lab. = Labour)

No. of Moulds	Labour.	Total Labour. Cost	Lab. Cost / Mould	No. of Cycles	No of Blocks/day	Days	Total Labour. Cost
1	**2**	**1800**	**1800**	**4**	**128**	**20**	**Rs35,156**
2	**2**	**1800**	**900**	**4**	**256**	**10**	**Rs17,578**
3	3	2700	900	1	96	26	Rs70,313
4	3	2700	675	1	128	20	Rs52,734
5	**5**	**4500**	**900**	**4**	**640**	**4**	**Rs17,578**
6	5	4500	750	1	192	13	Rs58,594
7	6	5400	771	1	224	11	Rs60,268
8	6	5400	675	1	256	10	Rs52,734
9	7	6300	700	1	288	9	Rs54,688
10	7	6300	630	1	320	8	Rs49,219

explains the optimum number of the mould into a block manufacturing process can be increased by increase the number of labour into a number of the mould by using the table five, such one mould per ten sites with two cycles per day employing three labour per cycle. Then, however, it was found that labour plays an enormous cost when manufacturing mud concrete block. Therefore, the efficiently managing labour is important when optimizing manufacturing process for mud concrete block. Thence the labour cost into total production was optimized by simulation another process of calculating total cost two thousand five hundred of mud concrete blocks., Costs were minimized when labour was increased to five with five mould and for four cycles per day. (Table 4). Costs can also be minimized in a large number of cases by mass production. Mass production is important for manufacturing a big number of MCBs.

However, as the Table shows, the best combination for manufacturing MCBs in mass scale is the use of five labour per mould and five moulds per cycle.

Manufacturing framework for Building MCBs.

Manufacturing MCBs

Table 4. shows the optimum number of moulds for a number of labour combinations. MCB manufacturing can be increased by increasing labour and moulds as seen in Table 4, but labour costs for MCB manufacture may then become enormous. Therefore, labour costs are important when optimizing the manufacturing process for MCBs. When labour costs for total production was optimized by simulation, another process for calculating total cost of two thousand five hundred of mud concrete blocks could also be used (Table 2).

After optimizing the best labour combination for the manufacturing mud concrete block, the methodology of building mud concrete block was optimized using previous research which determined the best sieve size and cement percentage for building MCBs.. A flow chart for the MCB manufacturing process was developed to show the entire process (Fig. 1)

The process starts with extracting suitable soil for manufacturing MCBs. Not all soil is suitable for manufacturing MCBs. Soil can be tested using a sieve test and should be carried out in a laboratory. The University of Moratuwa has the capacity of testing soil and detrmining its suitability for manufacturing MCBs.

The extracted soil is then mixed with cement as the first step. Water is added and the mixture poured into a mould made of steel sheets or wooden sheets. Using steel sheets 28 blocks can be made at once. The proper mixture can be identified by considering its consistency. After moulding the mud concrete, it should be allowed to dry for six days. in a dry location where the drying process and chemical reactions can take place at the same time. During this period, water can be poured into the MCBs to change the moisture content in order to increase the strength of the MCBs.

Results and discussions

MCB is an obvious low-cost product to replace the existing brick and cement block. Best mix proportions of Mud concrete blocks were determined to be a minimum of 4% cement, maximum 10% (sieve size ≤ 0.425mm), Sand 55-60% (sieve size between 0.425mm and 4.25 mm), Gravel 30-35% (sieve size between 4.25mm and 20 mm), Water requirement 18 - 20% of the dry mix.

Cost optimization was carried out after a series of experiments using scenario-based optimization techniques. Experiments were done in real world context using real man hours and real materials in order to understand how the "economics of scale" work. The manufacturing mould was optimized by using a series of optimization linear calculations. They showed that 28 blocks can be made from one steel sheet. And two sets of blocks per two sheets was the best combination for building moulds.After optimization MCB moulds, the manufacturing framework was introduced. The process was designed by considering a. Strength, b. Material availability c. Labour and Mould combination (economics of scale) and d. Drying process.

The process was simulated and optimized into a seven step diagram for manufacturing MCBs. It was as simple as manufacturing cement blocks or bricks. However, costs were less for MCBs as the process was less complicated. A proper costing calculating sheet was developed using simulation and optimization data collected. It was found that a 200 mm x 150 mm x 300 mm MCB could be manufactured for Rs.9.85 while a cement block of the same size costs Rs.35.00, making a 70% cost saving in the construction of walls of similar calibre.

References

1. C. Prabhath and A. Nanayakkara, *Concrete Technologies*, 2014.
2. *Twentieth-Century Building Materials: History and Conservation*. Getty Publications, 2014.
3. F. R. Arooz, A. W. L. H. Ranasinghe, and R. U. Halwatura, Mud – Concrete Block Construction , *Community centers for war victim communities in Batticaloa, Sri Lanka*, in Faculty of Architecture Resaerch Unit 2015 Sessions, *Making Built Environments Responsive*, University of Moratuwa, 186–200.
4. A. W. L. H. Ranasinghe and R. U. Halwatura, Performance of Mud Houses and Contentment in Sri Lankan Context, *Ann. Sess. Inst. Engineers, Sri Lanka*, 2014, 69–76.
5. G. Norman, *Economies of Scale, Transport Costs, and Location: Studies in Applied Regional Science Series*. Springer Science & Business Media, 2012.
6. G. A. Carlino, *Economies of Scale in Manufacturing Location: Theory and Measure*. Springer Science & Business Media, 2012.
7. C. C. Pertsova, *Ecological Economics Research Trends*. Nova Publishers, 2007.
8. C. A. van Iperenburg, *Return to Scale and Substitution for Small and Medium-sized Business In Structural Engineering*, 1985, Research Institute for Small and Medium-sized Business.
9. C. M. Pagoso, R. P. Dinio and G. A. Villasis, *Introductory Microeconomics*, 1997, Rex Bookstore, Inc.
10. D, Bertsimas and J. N. Tsitsiklis, *Introduction to Linear Optimization*, Athena Scientific, 1997.
11. M. Islam, Use of Material in Residential House Design: An Optimisation Approach Balancing Life Cycle Cost & Life Cycle Environmental Impact, Ph,D. Thesis, RMIT University, Melbourne, Australia, 2012, https://researchbank.rmit.edu.au/view/rmit:160417
12. B. Goertzel, N. Geisweiller, L. Coelho, P. Janičić, and C. Pennachin, *Real-World Reasoning: Toward Scalable, Uncertain Spatiotemporal, Contextual and Causal Inference*, Atlantis Press, 2011.
13. J. S. Kleinfeld, The small world problem, *Society*, 2002, **39 (2),** 61–66.
14. J. M. Smith, S. B. Gershwin and H. t. Papadopoulus, Performance evaluation and optimization of production lines. *Annals of Operations Research*, **Vol 93**, 2000, Baltzer Science Publishers, Bussum, The Netherlands.
15. Process Simulation and Optimization in Sustainable Logistics and Manufacturing (eds. P. Pawlewski and A. Greenwood), 2014, Springer, Switzerland