Describing building sustainability innovation potential – Block making in Tanzania and Uganda

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Abstract

Purpose. This paper describes opportunities for sustainable building in East Africa. Previous research indicates that cement is often poorly used in the commonly used concrete blocks. Better use of cement and thereby lower costs and a lower carbon footprint might be achieved by substituting solid blocks with hollow ones while sustaining functional requirements. This work could further be advanced by a business model that promotes affordability and a lowered carbon footprint of blocks produced at building site.

Methodology. Block manufacturing processes in Tanzania and Uganda are described. Sustainability performance as price and carbon footprint per wall m^2 are assessed and compared for solid and hollow concrete/sandcrete blocks.

Findings. The results from Uganda indicate that there is a clear economic and environmental advantage in using hollow blocks compared to solid blocks. There seems to be innovation potential to be realised both in choice of product and improvement of manufacturing processes. The preliminary findings indicate that costs per m^2 of wall could for 6 inch blocks of the same functional quality be reduced with some 20% and the carbon footprint with 40% when using hollow blocks instead of solid ones. In Tanzania only a carbon footprint saving potential of about 30% has been inferred.

Practical implications. The results indicate that in order to assess overall global improvement potential, sustainability needs to be understood on the operational level.

Originality/value. The results contribute to the development of more sustainable building blocks in the context of East Africa.

Keywords
Sustainability; concrete; sandcrete; hollow block; cement productivity; Africa.

1. Introduction

Change Management capability for sustainable development is urgently needed. Many areas need radical change. One of them is providing shelter - a basic global need. Concrete is the most common man-made material and provides solutions for all types of buildings from simple to complex. Concrete plays a pivotal role in providing affordable shelter. Unfortunately, concrete also comes with a substantial carbon footprint, mostly from the Portland Cement, used as the binder in concrete. The World Business Council for Sustainable Development (WBCSD) roadmap for low carbon transition in the cement industry (WBCSD, 2018) estimates that about 7% of global carbon emissions originate from cement. Most new buildings are built in developing countries where populations are growing as are demands for more living space. Africa faces significant challenges with providing affordable buildings with low carbon footprints. Since financing is mostly a problem, houses are often built over periods of several years. Block based building materials, permitting incremental building, prevail. Market for building materials is strongly price driven. Quality, too, is cost based. However, habits and cultural preferences also play a role. E.g. in Tanzania, only solid concrete blocks are used for building of one family houses. Conversely, in Uganda, hollow blocks are integrated in construction to reduce construction cost. Globally, when concrete blocks are used, hollow blocks seem to be dominating because they can be produced cheaper for providing the same functionality, e.g. as a m^2 of house wall. But solid blocks are easier to produce giving less damages.

The choice of block design as solid or hollow has an important impact on product price, construction productivity and material consumption. Hollow blocks reduce the amount of material needed and increase labour productivity. Moreover, there are strong indications that hollow blocks achieve the functional requirements of walling units. Still, the change from solid blocks to hollow blocks seems to be slow, especially in Tanzania, but also to some extent in Uganda. The indication is that there could be both technical and cultural thresholds for the change from solid to hollow to take place. In Dar es Salaam, one family houses are built with 5- and 6-inch solid blocks. For anybody to decide to change the solid blocks used in a house, an investment which most probably is the biggest investment in life, would be highly unexpected. This leads to little or no demand of hollow blocks and, consequently, into a low level of know how in producing hollow blocks. The changes when going from solid to hollow are not dramatic but there are some issues like the material mix where some addition of aggregates seems to be needed to increase cement performance. Most block producers both in Tanzania and Uganda are small units with limited access to funds, technology and know-how. The business concept is based on doing what customers ask for and the role of innovation for both process and products is low. This means that the rate of change is low, which, seen from the perspective of sustainable development, is a problem. Yet the growing gap in supply and demand of housing in all Sub Saharan Africa (SSA) demands a trend of innovations that will deliver sustainable development.

Like in Dar es Salaam, the size of choice for a block in Uganda is the six-inch (150mm) thick type. Both solid and hollow forms are common but, given that hollow blocks tend to be significantly cheaper than solid ones, hollow blocks are preferred when they meet the functional requirements of strength, stability and durability of walls. Because the hollow block is light and demands less materials in construction, its labour productivity is higher than that achieved using solid blocks. The benefit of increased labour productivity is important. Sustainable housing is not only driven by design requirements, materials and financing but also by materials management, labour productivity and construction technologies. One important issue is the logic for placing the production unit. The typical concept is having a fixed plant location. The alternative to this is having a mobile plant that uses local materials. This leads to savings of costs and reduction of the carbon footprint.

In Dar es Salaam it seems that none of the smaller or medium sized block producers apply any Quality Control. Only leading producers keep track of their strength performance. Having performance data - facts - is a prerequisite for improvement. Improvement of both quality and sustainability require measurements. There should be opportunities for business in producing cheaper building materials leading to an increased market share, for climate with a lowered carbon footprint, for customers, in receiving cheaper products and there should also be opportunities for employment.

The overall question is how change towards more sustainable building materials could be worked with? In this specific case the question is how could a best block production practice using as much of local technology and especially local manpower be introduced in combination with blocks that make best use of cement resulting in cheaper and more climate friendly products?

The first step in making any change happen is understanding how the situation is and generally defining what sustainability means in the context. In order to be able to improve, it must be possible to measure performance. The perfect process could be described as doing the right thing in the right way. In this context the right thing seems to be the hollow block and the question then is how to produce this in the right way.

The purpose of this study is to understand sustainability in the studied system and to highlight opportunities for improving the level of sustainability. Focus is on blocks used for buildings in the context of Tanzania and Uganda and the scope of the process studied is from concrete building materials to ready blocks on the building site. The following research questions (RQs) have been formulated:

RQ1: How could sustainability be measured, and benchmarks set in the studied systems?

RQ2: How could the studied systems be visualised?

RQ3: How is the sustainability performance of blocks in Tanzania and Uganda?

RQ4: Which strategies could be applied to speed up change?

2. Theory background

2.1. Description of the systems studied in Tanzania and Uganda

Tanzania and Uganda are typical, relatively poor Sub Saharan African countries. Tanzania has a population of 57 million (2017), which is rapidly growing and the prediction for 2030 is a population of 83 million (Populationpyramid, 2019a). Uganda has a population of 42 million (2017) and is predicted to grow to 62 million by 2030 (Populationyramid, 2019b). In only 13 years these two countries will have a predicted total population increase of almost 50 million people. This puts considerable pressure on change management for sustainable buildings. The systems studied form part of the larger African system of providing shelter, which as a subsystem has production of concrete blocks see Figure 1.

In Dar es Salaam, mostly sand, cement and water are used without the addition of stone aggregates. The materials are mixed together and put into a mould and are then compacted. These blocks are called sandcrete blocks and are mostly 6-inch wide (about 150mm). The production provides jobs with low skill requirements. In the simplest case production of blocks is carried out manually with the only equipment being a manual compacting machine - a Bam-Bam, which can be produced locally, and which is in Dar es Salaam sold to a price of about 200 US$. However, most blocks sold in Dar es Salaam are so-called vibrated blocks which are produced using a simple pan mixer followed by a vibrating machine that helps compacting the blocks. This type of equipment costs about 5000 US$ and requires electricity. In Dar es Salaam the main investment cost is the plot. The number of production units in Dar is hard to estimate but could be about 1000-2000 small producers employing in average about 10 persons each. The simple technology provides work for unskilled labour.

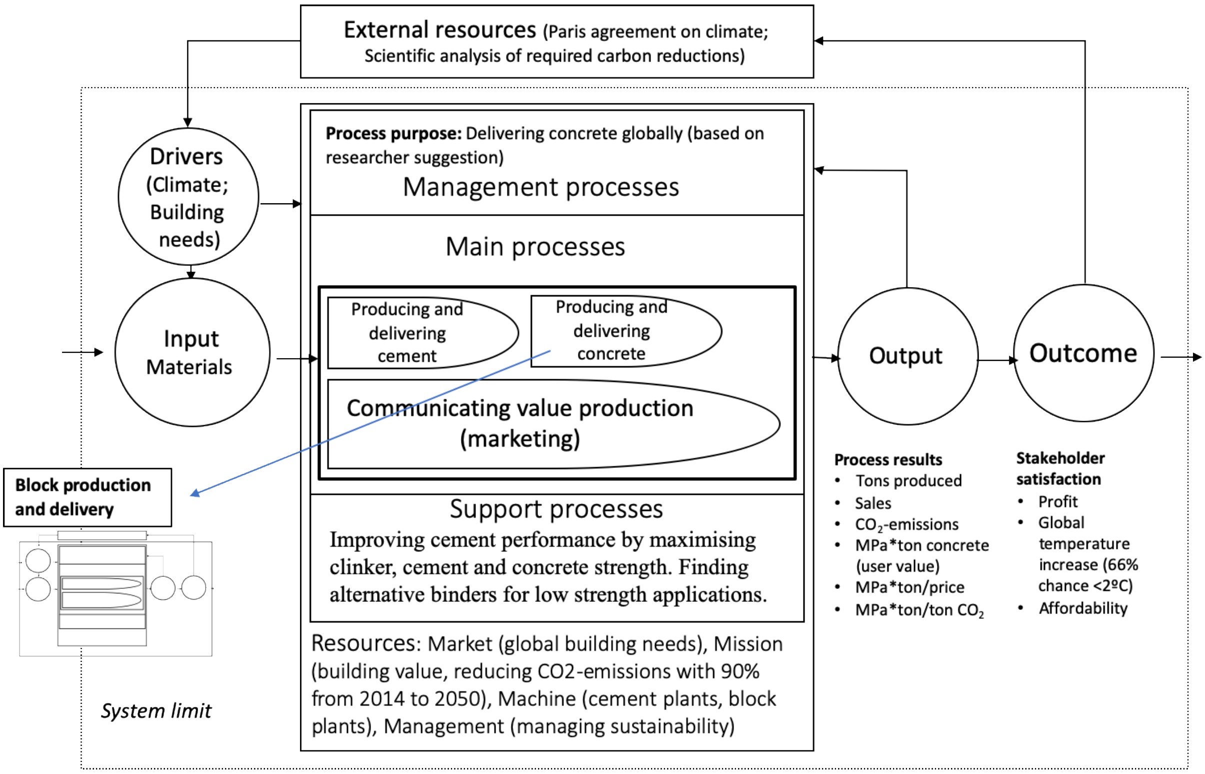
In simple local production with low level of technical equipment and cheap labour the cost of cement becomes dominating. In a typical six-inch solid block sold, both in Dar es Salaam and the whole of Uganda, the cost of cement is about 20-30% of the sales price. This, favours minimising of the cement content to lower costs. The problem is that the cement productivity drops quickly when cement content is lowered, especially in sandcrete blocks. The cement productivity indicates how well the cement strength potential is used and can be expressed in compressive strength*tons or Megapascal*tons (MPa*ton) (Isaksson and Babatunde, 2017). This indicator can be simply calculated by dividing the compressive strength in MPa with the proportion of cement in the mix. A typical concrete would be about 270 MPa*tons where as sandcrete blocks often are only about 70 MPa*tons or about a quarter of the benchmark (Isaksson and Babatunde, 2017). This means that most part of the cement strength potential is lost which increases building costs and the carbon footprint of buildings. The reason for the cement productivity dropping is that sand needs water to be properly compacted. This amount of water is much more than is needed for the cement reaction. In concrete the water - cement ratio should be low to make full use of cement strength. Water to cement (w/c) ratios of about 0.5 result in high strength. Sand could require up to 10% of water to enable proper compaction. When using only 5% cement this means a water-cement ratio of 2 and a strength which is about 15% of the level of w/c of 0.5 (Isaksson and Babatunde, 2017). Water demand can be reduced by using more aggregates, which normally increases cost or by using better compaction equipment which also makes production more expensive since this type of equipment needs to be imported. Increasing cement content will reduce the water-cement ratio and result in much stronger blocks. However, the market is not prepared to pay for the increased performance. Essentially, solid blocks, especially with high sand content - sandcrete blocks - seem to be a dead end for making better use of cement in the form of higher cement productivity. When shifting from solid to hollow blocks these can have the same outer dimensions providing the same functionality in a wall. The hollow block has less material per volume. This means that the cement percentage could be increased without increasing the amount of cement used per m^2 of wall. This reduces the w/c ratio and increases cement productivity. Therefore, hollow blocks should have some advantages compared to solid blocks.

Solid blocks in Uganda are made with Portland cement, water and a blend of quarry dust and an all-in aggregate of size 9.5 mm. Addition of the all-in aggregate tends to reduce the specific surface of the mix leading to reduced water demand, lower w/c and better cement productivity. However, the value gain does not compare with the benefits of using hollow blocks. Hollow blocks in Uganda are made from a blend of quarry dust and natural sand, the all-in aggregate of size 9.5mm is avoided because of high breakages in production due to thin sections (25mm thick) that require aggregates of finer sizes. Both centralised and site-based production approaches with semi-automatic electric machines of different production capacities are common in Uganda. The centralised method where permanent block factories are established, an approach common in Europe, creates an extra logistical cost of transporting blocks to construction sites. This is because the established block factories are not necessarily located at the sources of raw materials but deliver the raw materials at a cost similar to that of delivering the same materials to construction sites.

2.2. Change management with process-based system models

Companies could be described as systems. They could also be described as processes as is done in Figure 1 (Isaksson, 2019). The proposed system model includes five types of measurements that are input, output, outcome, drivers and resources, see Figure 1. All these indicators can be used to describe the current state of the system. Logically the description starts “outside in” based on process thinking. This means that outcome should be studied first and then the output that leads to outcome. Comparing the current performance with a benchmark results in a first appreciation of the existing improvement potential. A clearly presented improvement potential could then be used to create a sense of urgency for change that could drive and speed up the change.

Figure 1. The process of providing concrete as a network based on the Process Based System Model (PBSM) with the studied process of “Block production and delivery” as a subprocess under main processes.



Source: Based on Isaksson (2019).

The change process can be described using the elements of the PBSM presented in Figure 1. The change process can be divided into creating interest for change and improving processes. The first step in creating interest is the process of establishing a sense of urgency. This could be done by presenting a good opportunity for improvement which would become a driver for change. This is described in Figure 2 that could be seen as a support process in Figure 1. The work is iterative. Opportunities are presented to those in charge to establish a sense of urgency. This might have to be done several times. When there is an agreement to start changing the process should start from a new diagnosing that involves those concerned. This becomes a new iteration of the first Opportunity Study of diagnosing, analysing and solving, see Figure 2. The opportunity could consist of a defined improvement potential, a description of causes for its existence and proposed solutions (Isaksson, 2015).

3. Method

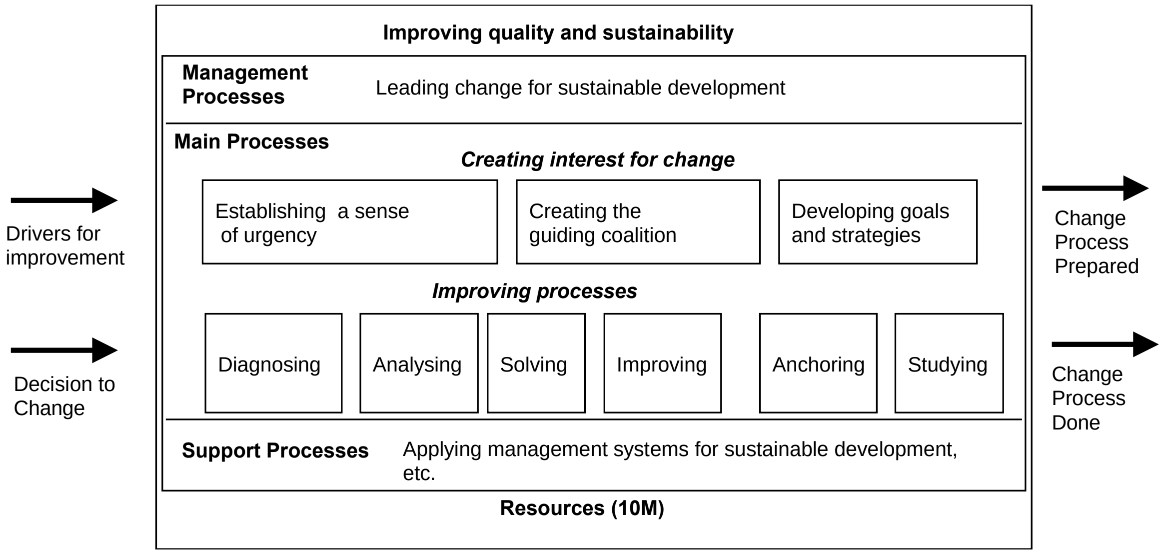
The answer to RQ1 of how to measure and set benchmarks for block sustainability is for the part of doing the right thing mainly based on cement productivity proposed in Isaksson and Babatunde (2017). There is also further development based on Isaksson (2007) that propose how to assess strength performance as a combination of average and variation. Doing the thing in the right way is discussed by studying the manufacturing process and identifying main stakeholders from a sustainability perspective.

The RQ2 on visualising systems is answered by using the PBSM presented in Isaksson (2019) with proposed relevant output and outcome indicators for the block production systems.

The RQ3 on the current performance of blocks is for Tanzania answered presenting block strength data from previous research presented in Sabai et al. (2016) which has been reanalysed. For Uganda data from only one site has been studied.

The RQ4 on strategies for change, is based on a discussion on results from RQ3 and on the production process innovations tested in Eco Concrete.

Figure 2. A generic change process based on the elements of the PBSM-model.



Source: Based on Isaksson (2006; 2019).

4. **Results**

4.1 How to describe block sustainability and how to set benchmarks

Isaksson and Babatunde (2017) suggest that concrete building value can be expressed in terms of strength tons MPa*tons. Using a relative figure of value per harm this could then be expressed in comparison with carbon footprint (Planet harm) and price (People harm), (Isaksson et al. (2015). See also suggested output KPI in Figure 1. Isaksson and Babatunde (2017) propose a benchmark of 270 MPa*tons based on cement in standard mortar used for strength testing of cement. A target compressive strength for blocks of 5 MPa is set as an example. This strength meets the minimum requirements in block standards such as the TZS 283 (2002) in Tanzania that requires 4 MPa. The cement percentage in the mortar test is 22% for a strength of 60 MPa. Assuming that this an be scaled down without any losses it should be possible to achieve 5 MPa with 5/60 of 22% which is about 1.8%. This would be at 100% relative cement productivity or 270 MPa*tons.

Generally, variability is a quality issue. The higher the variation, the lower the customer value. In a wall the weakest block could be seen to set the performance. From the point of building wall functionality, a suitable unit of comparison could be a m^2 of wall defining the cost and the carbon footprint of it. Having the sufficient functionality depends mainly on having sufficient compressive strength of the blocks used. Isaksson (2007) suggests using the cement standard EN 197-1 logic of the L-value. In the L-value both the average and variation are merged into one figure. The L-value stands for the level where 95% of values are higher. This is calculated as:

L= average - kA*s

The constant kA depends on the number of values and is 2.4 at n=20. In the EN 197-1 n=20 is the lowest value included. The higher the n, the lower the kA is. The L-value can be seen as proxy for the user value. In this paper we use the kA as 2.5 if n is not known. This is because the number of samples often has been relatively low. This provides us with a first estimate of how variability affects user value. There is no established benchmark for the variability and the s-value. In data from Tanzania Bureau of Standards, collected in 2015 for Sabai et al. (2016), out of some 100 studied samples the coefficient of variation was in average 22%. The best 10% of the samples have a coefficient of variation less than 10%. Based on this a benchmark of 8% as relative variation is chosen. Using the 270 MPa*tons with 8% means that the s would be about 22 MPa and the LMPa*ton target = 250-2.5*22 = 195.

Translation of the block performance to functional wall performance requires that the wall carrying load is defined and translated into a block strength. This depends on the dimensions of the block. Here the assumption is made that a 6 inch wide hollow block with 5MPa and a maximum of 50% hollow area meets the functional requirement. This corresponds to a solid 6 inch block with a strength of 2.5 MPa and an approximate carrying load of 30 tons per meter of wall. The block area as height times length defines how many blocks are required per m^2. Here, the calculations are done without accounting for joints with the argument that focus is on the comparative performance of blocks.

Table I. Proposed benchmarks for block and wall technical performance

Item	Benchmark
% cement	1.8
28 day target (MPa)	5
MPa*ton	270
LMPa*ton	195
kg CO2/ton cement	700
kg CO_2/m^2	2.3
Volume of wall m3	0.15

Cement types vary in clinker content. Clinker is the burnt material from cement kilns which provides the strength, and which also is responsible for the main part of the carbon emissions. The clinker content therefore largely defines the carbon footprint of the cement used. Here the figure of 700 kg CO_2/ton of cement is used which in Isaksson and Babatunde (2017) is presented as benchmark. In Table I theoretically assessed benchmarks are presented. The weight of the wall has been calculated based on a bulk density of 2400 kg/m^3 which then permits assessing the carbon footprint.

4.2 Block performance in Dar es Salaam

In the case of Dar es Salaam, production is firmly anchored in solid sandcrete blocks. These are familiar to everybody and the materials are easily available. Out of some 100 blocks randomly collected from 35 different producers in a study in Dar es Salaam in 2015 about 80% were solid 6-inch blocks. The typical mix for blocks is having about 5% cement for solid blocks and about 7% for hollow blocks. In Table II performance results are presented. The results indicate a high variation which in relative terms is about 30%. This reduces the L-value. The indication is that a more stable production could improve customer value while possibly reducing production costs.

Table II. Results for blocks collected from different producers in Dar es Salaam in 2015.

	n	Average strength	stdev	Cem %	kA	MPa*ton	LMPa*ton
Solid (S)	74	3.34	1.25	5	1.99	66.8	17.1
Hollow (H)	6	3.83	1.3	7	2.5	54.7	8.3

Source: Analysis of data used for Sabai et al. (2016)

In order to be able to present comparative performance of solid and hollow blocks for the data from 2015 a few assumptions have been made. The typical 6-inch solid block with the dimensions of 6*9*18 inches typically weighs about 30 kgs. The hollow block weight depends on the size of the hollow and could be 50 to 70% of the solid block weight. Here, the hollow blocks have been attributed the weight of 20 kg. The wall area is 9*18 inches per block which translates to 9.1 blocks per m^2. Prices for blocks vary as does the price relation between solid and hollow blocks. Often hollow blocks are slightly cheaper. The prices attributed are 1700 Tshs for solid blocks and 1500 Tshs for hollow blocks. The exchange rate of 2200 Tshs per US$ has been used for presenting the results in Table III.

Table III. Block performance of results in Table II in terms of price and carbon footprint per m^2.

	Price US$/bl	Cost cement and sand	kg cement	Block weight (kg)	Cem %	kg CO_2	US$/ m^2	kg CO_2/m^2
S	0.77	960	1.5	30	5	1.05	7.03	9.6
H	0.68	736	1.4	20	7	0.98	6.20	8.9

Source: Based on data collected in Dar es Salaam 2018-2019

The results indicate that performance in terms of price and carbon footprint per m^2 is similar for solid and hollow blocks. When looking at material costs there is a difference with those for hollow blocks being lower. However, the difference is going to be reduced since some 10-20% of the sand should be replaced with aggregates to improve performance. It is unclear if aggregates have been used in the blocks tested. The results indicate that from a customer perspective the benefit is limited and most likely not sufficient to drive a shift from using solid to using hollow blocks.

Table IV. Results from top performers for strength and carbon footprint of Solid (S) and Hollow (H) blocks.

	MPa*t	LMPa*t	MPa	kg cem	Block weight (kg)	Cem %	kg CO2	kg CO2/m2
S1	280	109	18.2	2.2	34	6.5	1.55	19.8
H1	159	60	13.7	1.7	19.6	8.6	1.18	14.9
S2	127	85	6.1	1.8	36.5	4.8	1.23	11.8
H2	108	75	6.	1.6	25.1	6.3	1.11	10.6

			8					

Source: Based on data collected in Dar es Salaam 2018 from company A and B.

In Table IV results from two top producers A and B are presented. The cement content is only marginally higher than in Table II results, but strength results are much higher showing a 5 to 10-fold improvement in the L-value. This indicates a huge potential in improved cement productivity. However, the footprint per m^2 wall is about the same as for the low performing blocks or even slightly higher. The entire cement productivity improvement has gone into improved product quality.

The top producers A and B use less sand and more aggregates and have imported equipment with good compression of blocks. They also have professional management and at least partly better payed personnel. This leads to the blocks having higher prices. There is no exact price information available but generally blocks from top producers would sell at higher prices than those from the common local producers.

4.3 Block performance in Uganda

The block sizes are slightly different in Uganda with the basis in mm instead of inches. Typical lengths and heights are 400 and 200 mm respectively with the width varying from 100 (4 inch) to 200 (8 inch) mm. The face area of the Ugandan blocks is slightly smaller compared to results from Tanzania and 12.5 blocks are required for a m^2. The block weight for solid blocks has been estimated using a bulk density of 2200 kg/m3. The hollow block weight has been set at 60% of the solid block weight since detailed information of size of hollows was not available, see Table V.

Table V. Prices and carbon performance results from Uganda, Eco Concrete Ltd plants

	Solid					Hollow				
Type (inch)	Ushs	US$	Block weight	US$/m2	kg CO2/m2	Ushs	US$	Block weight	US$/m2	kg CO2/m2
8	4000	1.08	35.2	13.5	23.7	2500	0.68	21.1	8.4	14.2
6	3000	0.81	26.4	10.1	17.8	2400	0.65	15.8	8.1	10.7
4	2300	0.62	17.6	7.8	11.8					

Source: Based on data collected from Uganda in 2019 from Eco Concrete

The largest difference in price per m^2 is noted for the comparison of solid and hollow 8 inch blocks. Here, the price per m^2 is 38% lower and the carbon footprint 40% lower per m^2. Also, the six inch hollow blocks perform better with 20% lower price and 40% lower carbon footprint. The results are indicative.

In Table VI some cement productivity results are presented. The data originates from Eco Concrete plants. Only results for solid blocks have been available. The original results were for strengths recorded at ages 7, 14 and 28 days. All results have been recalculated to correspond to 28 days. The 7 days have been set at 73% of 28 days This is based on some comparative data within the data set. The 14 days has been set at 90% of 28 days based on experience.

The performance of MPa*ton and LMPa*ton is good and close to the level of top producers in Dar es Salaam.

Table VI. Solid block performance based on samples from Uganda.

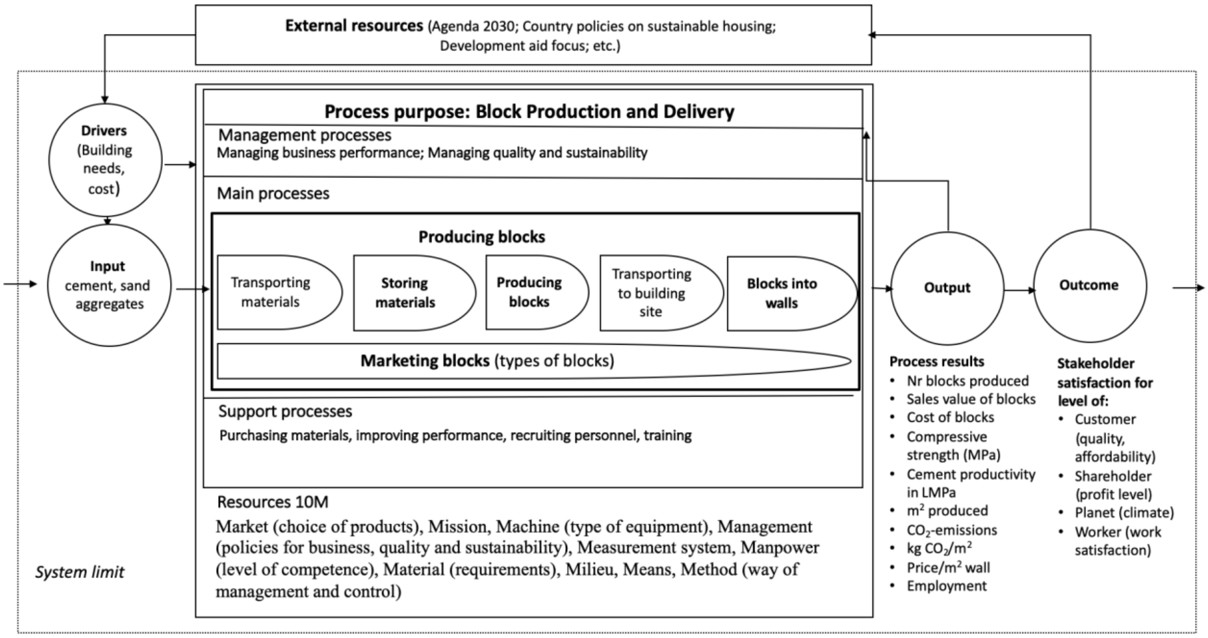
Type solid	Average 28 days strength (MPa)	Cem %	s	Mpa*ton	LMPa*ton
8 inch (n=25)	8.5	7.7%	1.3	110	69.5
6 inch (N=12)	7.9	7.7%	1.0	103	65.9

Source: Based on data collected from Uganda in 2019 and covering years 2015-2019

4.4 Describing production systems in Tanzania and Uganda

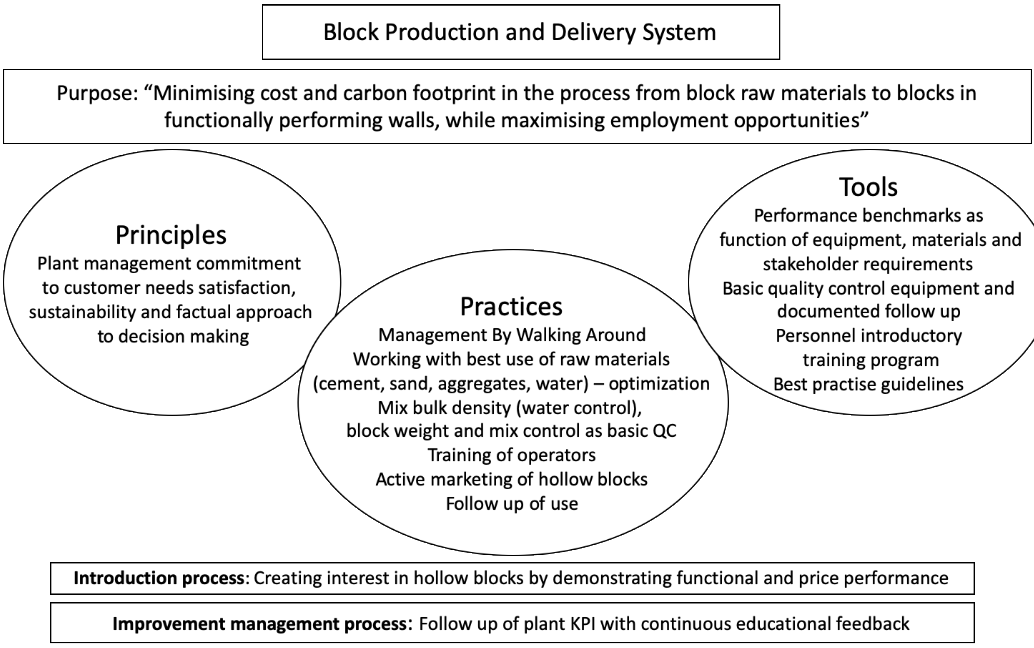
The typical block production value chains in Dar es Salaam and in Uganda have been described in Figure 3.

Figure 3. Block production systems in Tanzania and Uganda. In Uganda the producing blocks process consists of the processes in bold.



Source: Based on a development of Figure 1

Figure 4. Management system based on the Principle, Practices, Tools (PPT) system model.



Source: Based on Fredriksson and Isaksson (2018).

For the studied process in Uganda the blocks are produced at the building site where also the bulk of the materials is found. This avoids most of the process of transporting materials since materials at site are used. The mobile production equipment is set up at the building site. No systematic quality control is carried out.

In the companies studied in Dar es Salaam only the top producers have permanent records for quality. Most other companies only record number of blocks produced, sold and quantity of cement used. Mostly there is no clear follow up neither of the mix used nor of the block performance. In Figure 4 a proposed management system for a visionary block producer is presented.

4.5 Theoretical best block performance

The best performance should be something which is achievable using locally available materials and preferably also locally available technology. Testing has been carried out in a small site called Mama Kevin in Dar es Salaam that uses locally produced equipment. In normal production only sand is used. A hollow mould for producing 6 inch blocks has been tested. In the first test the ordinary mix with 5% cement and 95% sand was used to see if comparable results could be attained with hollow sand blocks. The mix normally used results in solid blocks with strengths ranging from 2-4 MPa at 28 days. The results for the six blocks tested resulted in a strength of 0.7 MPa at 14 days (about 85% of 28 days). The benchmark solid block needs aggregates. The following mix was tested:

Cement 5%
Granite crusher dust (0-5 mm) - 19%
Granite aggregate (5-10mm) - 57%
Sand - 19%

This resulted in an average strength of 5.5 MPa, and MPa*ton of 110 and an L-value of 3.7 MPa. This indicates that reasonably high performance can be achieved with locally produced equipment. The cost of production and the carbon footprint is compared in Table VII.

Table VII. Comparing benchmark 6 inch hollow block performance with 6 inch solid block performance.

	Cost US$/bl	kg cem/ block	Block weight (kg)	Cem %	kg CO2/ block	US$/m2	kg CO2/m2
Solid	0.43	1.5	30	5	1.05	3.9	9.6
Hollow	0.54	1.1	22	5	0.77	4.9	7.0

The cost increase is 26%. This is due to the fact that sand is much cheaper than the granite aggregate that needs to be hauled over a distance of more than 100 km. The CO_2-reduction opportunity per m^2 is about 27% and starts to be interesting. It should be possible to use limestone aggregate, but this has not been tested. Lowering the aggregate cost, which now makes up 50% of the material costs would make blocks cheaper.

4.6 Improvement potential and establishing a sense of urgency

The first sub-process in Figure 2 is “Establishing a sense of urgency”, which can be done by presenting a first iteration of a diagnosed improvement potential, the main causes for it and some ideas on solving - a quick DAS (Diagnosing-Analysing-Solving) (Isaksson, 2015). In the value network there are different stakeholders that view the urgencies differently. For the customers the main issue is price of blocks. Here, the diagnosed potential when going from solid to hollow blocks in Dar es Salaam, based on Table III, is only about 10% with the results only being indicative. Tests done also indicate that sand only is not an option for hollow blocks. Since the available aggregates are expensive costs risk of being higher for hollow blocks as indicated in Table VII. The results from Uganda presented in Table V and VI indicate that hollow blocks perform better in the studied market segment. However, the studied market segment seems to be for users with higher functional requirements. Comparing results from Tanzania in Table IV and VII indicate that kg CO_2 per m^2 is higher with the Ugandan blocks even when comparing with solid blocks. The reason is the much higher strength performance. There is a reduction of about 27% in carbon emissions when using benchmark hollow blocks instead of solid blocks based on some preliminary tests in Dar es Salaam. In Uganda there is a 20% cost reduction and 40% carbon reduction possibility for 6 inch blocks when going from solid to hollow. This might not be enough to raise any awareness on a national or a global level.

There is a much higher potential in increasing the cement productivity in terms of MPa and LMPa*tons. In Table VIII the average performance from Tanzania and Uganda has been presented. For Tanzania there are results from best performers and average performers. The results in Table VIII show that cement content generally is 5% or more. The theoretical benchmark of 1.8% cannot be realised. It seems difficult to reduce cement content below this while maintaining a low water to cement ratio. This indicates that even if hollow blocks could improve performance both with lower prices and lower carbon footprints that they are not an ideal solution for the climate part of building sustainability. The MPa*tons could with top producers occasionally be on benchmark, see Table IV. The LMPa*tons indicate a relative cement productivity of 5 to 50% and the MPa*tons a relative cement productivity of 20 to 80%. In spite of the low cement productivity the average Tanzania production emerges as having the lowest carbon footprint per m^2 and seemingly also the lowest price.

It could be that the strength target needs to be studied and redefined if it proves that sub-standard blocks can be used to build good enough houses, which seems to be the case in Dar es Salaam (Sabai et al. 2016).

Table VIII. Benchmarks for cement productivity and carbon performance compared with findings.

		Uganda		Tanzania	Top	Tanzania	Average

Item	Benchmark performance	Solid	Hollow	Solid	Hollow	Solid	Hollow
Cement %	1.8	7.7	7.7	5.7	7.5	5	7
Average MPa	5	8,2		12	10	3.3	3,8
MPa*ton	270	107		204	134	67	55
LMPa*ton	195	68		97	68	17	8
kg CO_2/m^2 (6 inch)	2.3	17.8	10.7	15.8	12.7	7	6.2

With a total expected population increase from 2017 to 2030 of almost 50 million people in Uganda and Tanzania there is an urgency in making better use of materials. The global average cement consumption in 2018 is about 600 kg of cement/person and year. The level of consumption is much lower in both Tanzania and Uganda. However, the needs are there, but these are constrained by economy. The additional cement needs for the population increase only, could be up to 30 million tons of cement until 2030. With 700 kg of CO_2 per ton of cement this translates into 20 million tons of additional CO_2-emissions. This could at the national and global level create some sense of urgency. However, the case for hollow blocks needs to be more convincing in order to act as a driver for change, at least in Tanzania. In order to make the change to be of interest for customers the blocks have to be cheaper by at least 10-20%.

On a global level a possible reduction of the carbon footprint with about 30% could be of interest to some organisations. However, further work is needed to see if the reduction could be further increased.

4.7 Improvement in the block delivery - a case from Uganda

In Uganda an innovative approach including mobile block production units and training in production and quality has been introduced by Eco Concrete Ltd. Eco Concrete Ltd is a medium sized enterprise that is involved in the manufacture of cement-based construction. The company utilizes technology and process innovation to provide a variety of cement based precast construction products. They primarily produce hollow and solid concrete blocks, and also pavers, pipes, cement floor tiles, retainers, high strength concrete, and Crib units. In appreciation of the firm’s distinctive approaches in the housing industry, Eco Concrete Ltd received a recognition award in 2017 by the United Nations Development Program (UNDP) and the Uganda Chamber of Mines and Petroleum in the category of Innovation and Value Addition to Development Minerals. Their business approach of installing industrial scale mobile plants at clients’ sites saves clients’ money to margins of up to 15% of direct construction cost. The firm’s ability to adapt to and manage changing site conditions and material sources to ensure that quality is sustained in all parts of Uganda is their competitive advantage. This is achieved through rigorous training of their machine operators and a team of workers who now reach 50 youths. The company operates a horizontal management model where all its workers are supposed to know everything about the regular production operations, which approach depersonalizes quality and productivity. The main stock of their employees are the youths who have been excluded from the mainstream education system. By skilling them in production processes, product development, machine management, records keeping, team building, work ethics and general running of concrete construction materials manufacturing, the firm empowers them with an opportunity to apply these skills for commerce within their communities. The employees of the firm that show exceptional talent are recruited on the ‘Eco concrete reward program” where a machine is dedicated to them for a period of two years production after which ownership is transferred from Eco Concrete Ltd to the machine operators. This empowers the semi-skilled youth to create more jobs and transfer skills to peers. The company runs a profitable operational model where, by shifting production to client's sites, they minimize production costs and increase competitiveness. Their management approach empowers employees to exit self-sustaining through the work of their hands, saves the environment and saves money for their clients through their production-on-site model.

Savings in the production processes of costs should be calculated into wall footprints. These have not been accounted for in the current study. Here, further work remains to be done.

5. Discussion

The work covers sustainability both at high and low levels with a broad perspective. The presented details of solid and hollow block performance are indicative where the main purpose is to describe how sustainability can be assessed at an operational level. The effects on costs and the carbon footprint when converting from solid to hollow blocks have been studied. The effects on employability have only been mentioned in the context of using imported or locally produced production equipment. The job and competence creating potential of the studied value chain needs to be further studied and should form a part of the sustainability assessment.

If the locally produced equipment can achieve an acceptable cement productivity meaning some 150-200 MPa*tons (compared to the benchmark of 270 MPa*tons) remains to be studied. In the few tests carried out with locally produced equipment the best performance has been on 110 MPa*tons. The effects on employability in using locally produced equipment also needs to be further studied.

The indicated improvement potential in practical terms is important at the level of carbon footprint and provided that the requirement is to produce blocks according to standards. There is a substantial potential in improving the cement productivity. However, this is not easy to convert into more functionality. The study confirms that cement productivity could be considerably increased measured both in MPa*tons (average value only) and in LMPa*tons where the variation is included. Top performers achieve LMPa*ton values up to 100 whereas the ordinary production might be only about 10. Even if the LMPa could be improved 10 times the improvement does not go into more functionality in the form of cheaper walls with a reduced carbon footprint. The improvement in Tanzania seems to go entirely into improved strength and durability in high cost buildings. The results from Uganda seem also to be for more high-end customers. The studied 6 inch hollow blocks have a cement productivity LMPa as 65-70 which is about 40% of the proposed benchmark 195. This is a good result, but still the resulting carbon emissions per m2 wall are higher than the average solid block in Tanzania. Translating the cement productivity improvement potential into more functionality at the current level of wall performance still needs more research. Generally, the data collected has some limitations. Especially for Uganda, the results come from only one company.

6. Conclusions

Below are the conclusions for the five Research Questions (RQs):

RQ1: How could sustainability be measured, and benchmarks set in the studied systems?

Block sustainability can be defined as the user value the blocks provide where the unit of comparison could be a square meter of wall. This value can then be related to price and to carbon emissions. The indicators proposed here are harm to value and are expressed as price per m^2 and kg CO_2 per m^2. This is the inverse to value per harm, e.g. sales vale per carbon emissions. The value benchmarks have been set as cement productivity in absolute and relative terms. The cement productivity benchmark was set at 270 MPa*ton in absolute terms and as 100% in relative terms based on Isaksson and Babatunde (2017). An absolute L-benchmark as 195 MPa*tons was proposed. The benchmark for carbon emissions per m^2 was set at 2.3 kg CO_2/m^2 wall based on 100% cement productivity in blocks with 5 MPa strength. This proved not to be realistic since the target cement content in that case becomes 1.8%, which is too low to permit a concrete that achieves 100% cement productivity. Here, more work is needed.

RQ2: How could the systems be visualised?

Process based system models can be used to describe the value chain and the proposed main indicators for output and outcome. The visualisation in Figure 3 describes the difference between the typical production processes in Dar es Salaam compared with the Eco Concrete process in Uganda. The main principles, practises and tools for sustainable block production have been suggested and presented in the PPT system model, see Figure 4.

RQ3: How is the sustainability performance of blocks in Tanzania and Uganda?

The performance in terms of cement productivity measured as MPa*tons and LMPa*tons are 5-50 and 20-80% respectively. Locally made equipment has in tests achieved 40% of the MPa*ton benchmark. The performance between the studied plant in Uganda and top performers in Tanzania is similar. The average performers in Tanzania have a significantly lower cement productivity but still sell cheaper blocks with a lower carbon footprint per m^2. This is by producing blocks with lower strength that often are sub-standard. However, from a functional point the blocks work and result in buildings that people seemingly are satisfied with. This could indicate that what constitutes the right target strength is not clear.

There is no obvious easy way to realise potential in Tanzania on the level of producing cheaper blocks with lower carbon footprint. However, cement productivity can be improved which will result in improved quality of blocks.

Results from Uganda described in Tables IV and V indicate that there could be cost savings of about 20% for 6 inch blocks and 40% for 8 inch blocks when converting from solid to hollow blocks. The carbon footprint could for both types of blocks be reduced about 40%. However, the carbon footprint is in the hollow 6 inch block from Uganda estimated to 10.7 kg CO_2/m^2 which should be compared with an estimated footprint of 7 kg/m^2 in Table VII for the test results of a 6 inch hollow block that comply with the Tanzania block standard. This could indicate that defining the target values for block strength based on the functionality needed might be able to save further costs and carbon emissions.

RQ4: Which strategies could be applied to speed up change?

In the Dar es Salaam market there are economic, technical and behavioural barriers. The main one is the economic. Even if cement content could be lowered when converting from solid to hollow blocks, the substitution of sand by aggregates needed increases the production costs. Since there is no demand for hollow blocks in the market for building one family houses there is little competence in producing the blocks in the best way. The strategy of change here is more education and better measurement of performance. The management commitment described in Figure 4 needs to be activated. Here, the way forward might be to demonstrate good results in practice. Work could be done with producers to create interest in hollow block production, but also working producers of hollow blocks to improve performance and to increase the market share.

In Uganda there could also be some scepticism towards hollow blocks. E.g. there are stories about thieves breaking walls to get into houses. Here, hollow blocks are perceived to be inferior. However, they are used for internal partition walls. Also, the changing construction forms to storied buildings that will need lighter walling units in upper floors is further driving the demand for hollow blocks.

In Dar es Salaam production development, with focus on producing the cheapest possible hollow blocks that meet standard and functional requirements, is needed. In addition, blocks need to be actively marketed as a more affordable quality solution for walls. More R&D is needed to better describe the improvement potential in terms of cost saving and saving of kg CO_2 per m^2. Finding cheaper local aggregates seem to be a key issue for block production in Dar es Salaam.

In Uganda the current concept of mobile production plants with training and quality control can be further developed and it could possibly also be tested in Tanzania. A light version of this idea could be to adapt and lease hollow block moulds in combination with training and introducing simple methods for quality control.

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