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A HOLISTIC MATERIALS DESIGN REQUIREMENTS FRAMEWORK (HoMDReF) FOR FUTURE HOUSING MATERIALS

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ABSTRACT: There is an unmet demand for affordable and sustainable walling materials for owner-builders in poor urban areas of the least economically developed countries (LEDCs). To ensure new materials meet needs, a Holistic Materials Design Requirements Framework (HoMDReF) is proposed which can assist researchers in new materials development.

Many rapidly growing countries in Asia and Africa have low economic development, with urban dwellers often living in inadequate housing. The lack of affordable, practical and sustainable construction materials is a significant barrier to achieving sustainable development.

Although several innovative materials have been developed that are more affordable and sustainable than “conventional” modern building materials, adoption has been very limited. Social science researchers have identified strong social, economic and cultural factors influencing the housing decisions by poor urban dwellers and these must be considered in addition to the technical and environmental factors usually focused on by researchers when developing innovative construction materials.

A multidisciplinary approach was used to identify the critical issues for walling materials for owner-builders in poor urban areas. Issues are presented in the HoMDReF under technical, environmental, economic and socio-cultural categories.

This problem-first approach has confirmed that the current techno-environmental focus of researchers is insufficient. Researchers must consider early on in the design how new materials will fit in with people’s values and the urban economic context.

KEYWORDS: design methodology; sustainable materials; urban poor; housing

1 INTRODUCTION

1.1 What are the problems in LEDC urban housing?

The problems of adequate housing in least economically developed countries (LEDCs) can be categorised into three main groups: scale of supply, quality of life and environmental impact. This article will focus solely on the regions of Africa and Asia, as this is where most population growth is expected to occur (see Figure 1) and where these problems are most acute.

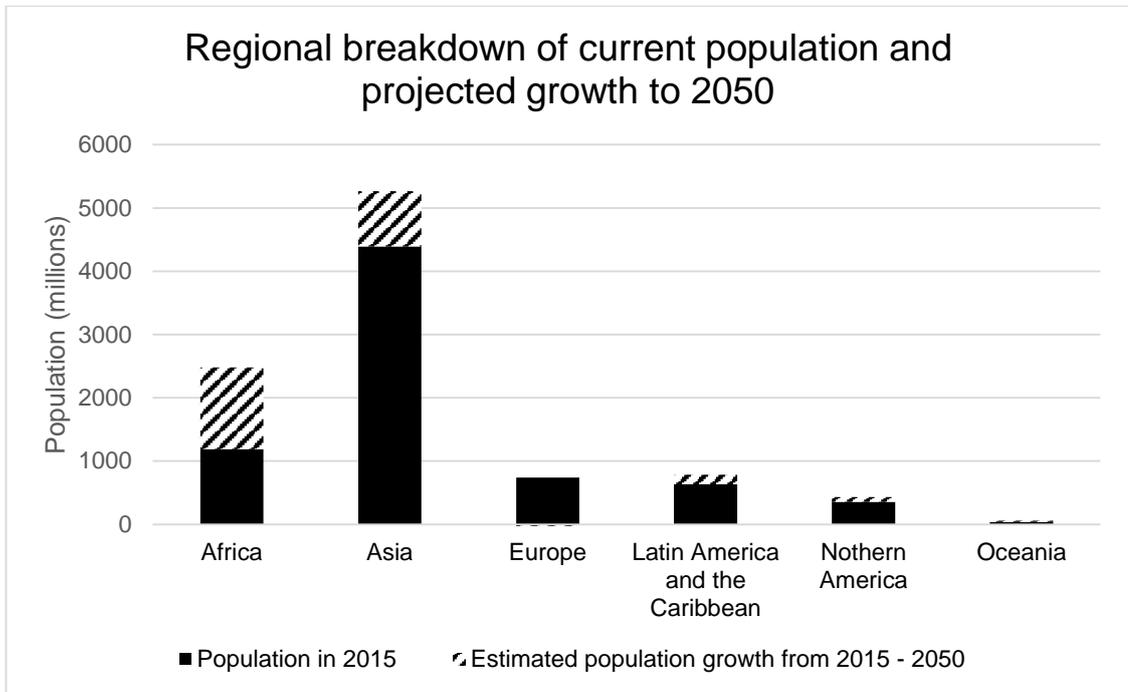


Figure 1. Comparison between regions of current population and expected growth to 2050. Produced using figures from (United Nations Department of Economic and Social Affairs, 2015).

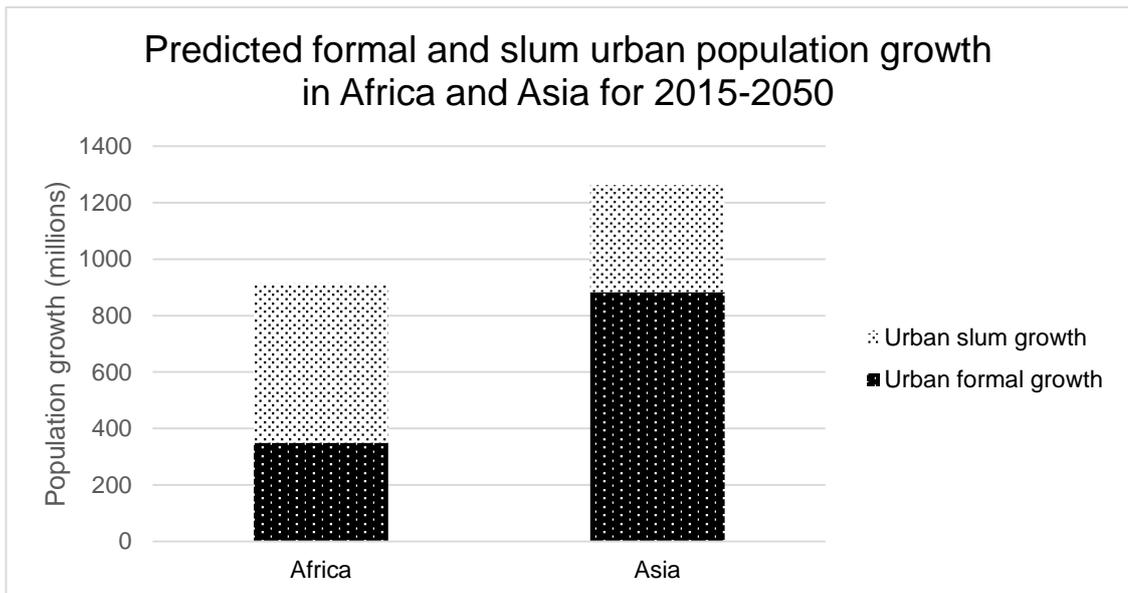


Figure 2. Predicted growth of urban formal and slum housing in Africa and Asia. Produced using figures from (UN-HABITAT, 2014; United Nations Department of Economic and Social Affairs, 2014, 2015).

Presently, there are insufficient adequate dwellings for the number of people living in urban areas. The UN estimates that as of 2012, 863 million people were living in slums in developing countries (UN-HABITAT, 2012). Looking forward to 2050, significant proportions of urban population growth in both Africa and Asia are predicted to be from slums. The informal sector dominates housing production in LEDCs (Du Plessis, 2002) and whilst the informal sector is very

effective at building dwellings at minimal cost, these are rarely adequate for people's fundamental needs (Aina, 1988), as suggested by the photo in Figure 3.

Although it is widely acknowledged that inadequate housing has a detrimental effect on wellbeing (Du Plessis, 2002), the impact of the physical nature of a dwelling on occupant wellbeing has received little attention. However, a study on Buenos Aires slum dwellers has related several aspects of inadequate housing to increased prevalence of specific physical and mental health impacts (Mitchell and Maccio, 2015).

Both traditional and conventional modern building materials often have undesirable impacts if materials are not sustainably sourced. For example, the demand for mangrove poles for thatching and reinforcement have had a significant impact on the coastal ecosystem in Tanzania (Wells *et al.*, 1998). Conventional modern building materials such as fired brick and concrete are often more resource intensive in LEDCs than in Western countries, owing to inefficient production, transportation and use. For example, firewood is often used for the firing of clay bricks in inefficient kilns (Hashemi *et al.*, 2015) in LEDCs while efficient and insulated gas operated kilns are used in more developed countries.

To reduce a building's embodied impact, one can either reduce the building's mass or reduce the embodied impact of the building elements. Although it would likely be possible to reduce the mass of materials used in dwellings through optimisation of the structural design, such a design-based intervention would likely be far harder to implement in practice compared to the introduction of alternative materials in a product-based intervention. This is due to the highly decentralised and unregulated nature of informal construction.

Inadequate urban housing in LEDCs is a multi-faceted and complex problem and part of this problem is materials based – neither traditional nor conventional modern building materials are sufficient for needs. There is an unmet demand for new materials which meet the specific needs of the communities in these areas.



Figure 3. An example of inadequate dwellings in the Mathare Valley area of Nairobi, Kenya. Unaltered image courtesy of Claudio Allia, via https://en.wikipedia.org/wiki/Mathare_Valley Licensed under Creative Commons CC BY-SA 3.0 <http://creativecommons.org/licenses/by-sa/3.0/legalcode>

1.2 Why has this demand for materials remained unmet?

Innovative materials which are technically and economically superior to both traditional and conventional modern building materials have existed for several decades, but have not been adopted in a significant way (UNCHS, 1993). Other factors beyond techno-economic considerations are behind this continued preference for conventional modern building materials. These factors can be categorised into three main groups: attitudes of home-builders, practical limitations of technology in the informal context, and previous research on innovative building materials.

The main criteria informing materials selection for home-builders are reported as: status and social prestige, durability and ease of maintenance (Okpala, 1992; Wells, 1995; Wells *et al.*, 1998; Yeboah, 2005). Despite cost being a very prominent constraint for the urban poor, the above factors have been reported to have greater importance than cost-effectiveness (Wells *et al.*, 1998). Indeed, estimates for the typical contribution of materials to the overall construction cost (excluding land) in LEDCs range from 60 – 80% (Wells *et al.*, 1998; Baiden *et al.*, 2014). Despite being more affordable, the majority of people in LEDCs do not want to live in traditional dwellings as they are considered not conducive to a modern lifestyle nor to sufficient social status (Wells *et al.*, 1998; Yeboah, 2005).

The result of this is a strong preference for conventional modern building materials, namely concrete blocks and fired bricks, for walling. This mirrors the material choices from more developed countries, even though the needs, material availability, construction methods and costs are very different. Despite these materials being frequently unaffordable to the urban poor, they are still aspired to (Okpala, 1992; Wells *et al.*, 1998; Yeboah, 2005). Many LEDCs have outdated and restrictive building regulations, often dating back to colonial governments policies and this has bred a cycle of conservatism with regard to materials and architecture, which maintains the status quo of conventional modern building materials being considered as desirable and robust (Okpala, 1992; UNCHS, 1993; Yeboah, 2005).

A key feature distinguishing housing production in LEDCs from those in more economically developed countries (MEDCs) is the dominance of the informal sector in both production of materials and construction (Du Plessis, 2002), estimated to provide between 60 – 90% of LEDC housing (Okpala, 1992). Advantages of the informal sector include its flexibility and its ability to utilise both skilled and unskilled labour (Okpala, 1992). The crucial outcome of this is that the informal sector can provide housing at costs far below what the formal sector can (Awanyo *et al.*, 2014). Disadvantages of the informal sector include: processes are often wasteful of materials and energy (UNCHS, 1993), safety practices are poor (Mlinga and Wells, 2002; Wells, 2007), transport is expensive (Wells, 1995), design can be poor (Yeboah, 2005), and adoption of innovative materials is limited by skills availability (Okpala, 1992), knowledge transfer and capital to invest in new processes (UNCHS, 1993).

As already described, predicted population growth contributions of LEDCs are predicted to be far greater than for MEDCs. However, research towards construction materials specifically for LEDC urban areas is disproportionately small to the scale and urgency of the issue. In addition, the continued reliance on imported conventional modern building materials is deleterious for LEDCs' development and rates of resource depletion (Du Plessis, 2002; Yeboah, 2005).

This economic argument is a strong addition to the environmental arguments for using locally available raw materials for construction.

1.3 Why is there a demand/need for a holistic approach to materials requirements?

It is clear that the housing problems of the urban poor are acute and are continuing on an alarming scale (UN-HABITAT, 2011, 2014; United Nations Department of Economic and Social Affairs, 2014). From the evidence available, no material currently exists which has the potential to meet all the essential criteria for being a widespread solution.

The findings from sociological studies and the observed failure of innovative technologies to gain market traction makes it clear that a technology-led solution will not be enough. In order to meet the myriad technical and environmental requirements as well as being an attractive prospect to home-builders, previous demographic studies have recommended that research and development should be values-led (Okpala, 1992). However, there is no existing practical framework to enable materials researchers to do this. The closely related field of architecture has set a successful precedent for this kind of holistic approach, thinking about human needs as well as purely technical matters. Figure 4 presents a summary list of the main points made in the Introduction.

1.4 Aims

A framework for a holistic approach to materials design and selection will be presented. This seeks to ensure that researchers can use the framework to identify all salient requirements in a locally-specific level of detail, whilst being flexible enough to be transferrable between locations and contexts.

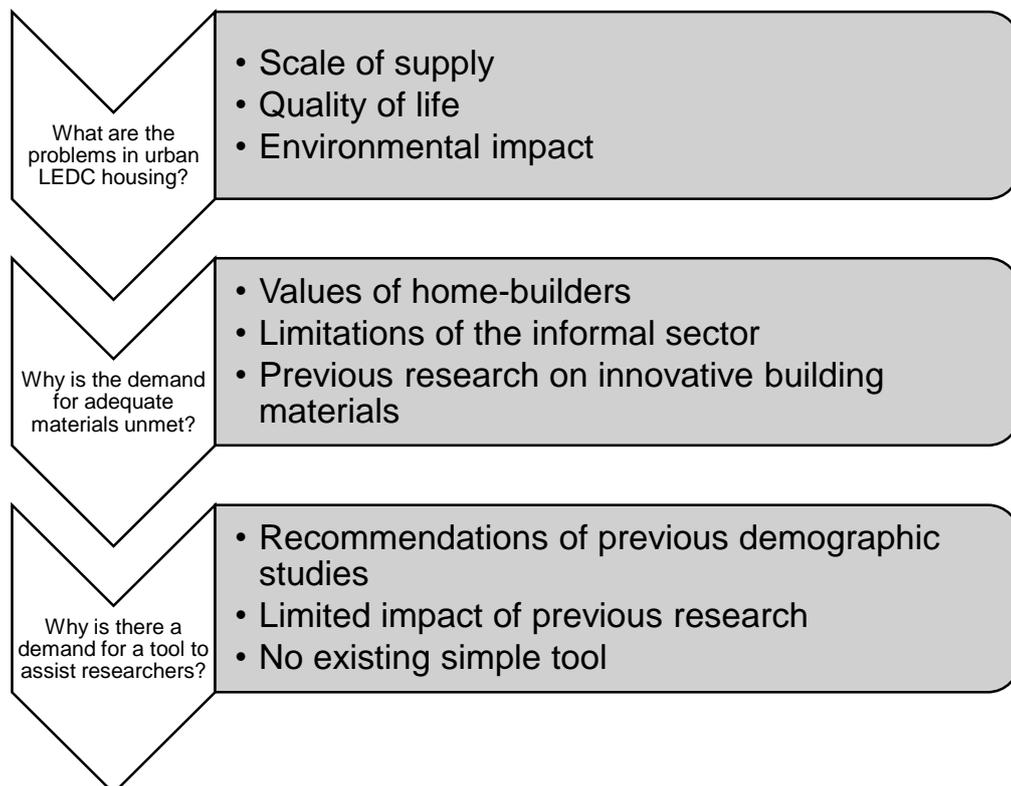


Figure 4. Summary list of main points made in Introduction section.

2 METHODOLOGY

2.1 Design of framework

Housing is a process, but is also a means to sustainable development. Sustainable development is a well-established concept, and can be used as a guiding light for this process. The three starting categories within this definition are economic, environmental and social (World Commission on Environment and Development, 1987), later joined by cultural (United Cities and Local Governments, 2010). For the purposes of this exercise, social and cultural categories will be condensed into a single socio-cultural category.

Values within these three categories can and should be optimised. Underpinning these three categories are fundamental technical requirements. This technical category is treated differently, as there is no benefit from over-engineering materials beyond what level of technical performance is needed, and over-engineering is likely to result in increased environmental impacts.

The HoMDReF is intended specifically for walling materials. Walling is typically the most impactful building element for this construction type and therefore has the most potential for improvement. Although the embodied energy of buildings has received much attention in scientific literature, only a small amount of these studies are on buildings similar to informally built dwellings. A study in India reported values for the mass and embodied energy breakdowns for load bearing masonry dwellings (1 and 2 storey height). The walls and supporting structure were estimated on average to contribute 39% of a dwelling's mass and 63% of a dwelling's embodied energy (Praseeda *et al.*, 2016). This makes the walls and supporting structure the most impactful building element.

3 THE HOLISTIC MATERIALS DESIGN REQUIREMENTS FRAMEWORK (HOMDREF)

The four categories in the HoMDReF are: technical, economic, socio-cultural and environmental. It is intended for this to assist walling materials researchers working to serve the needs of aspiring home-builders in a specific location. Some issues, and their requirements, will be very dependent on location. Identifying requirements for these issues would require consultation with the housebuilding community in that location. Other issues will likely be universally applicable.

Figure 5 illustrates the categories of requirements within the framework. Table 1 lists the suggested starting issues within each category, with an indication of whether each issue is straightforward to quantify.

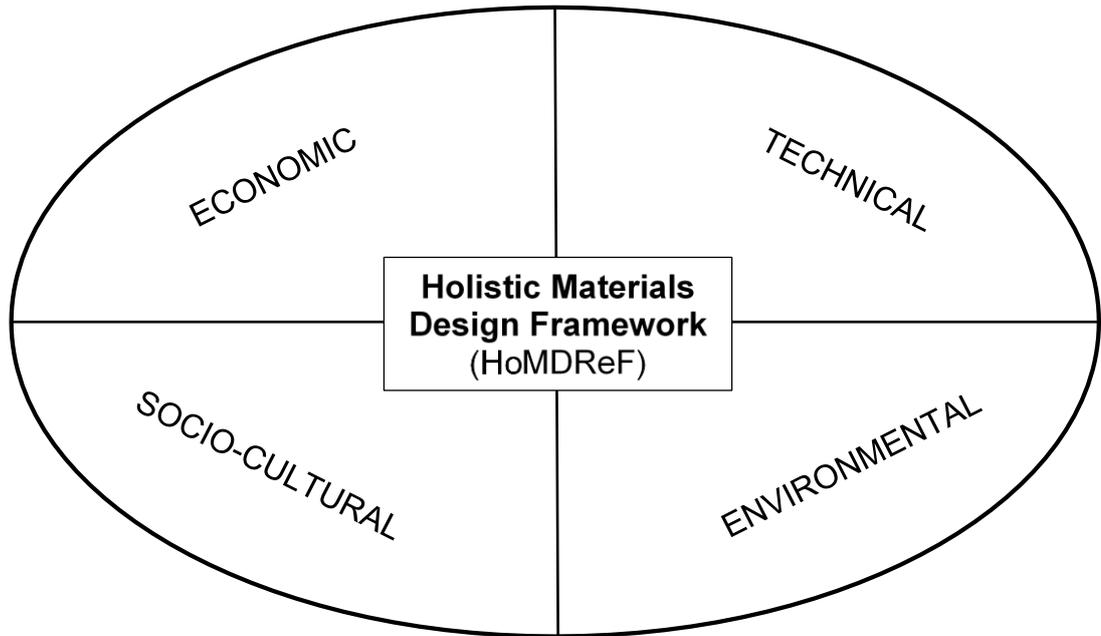


Figure 5. Diagram showing the different categories of issues in the HoMDReF.

Table 1. Table listing the suggested starting issues within each category. The extra column is marked with a Q if that issue is straightforward to quantify.

Technical	Q	Economic	Q	Socio-cultural	Q	Environmental	Q
Dry strength	Q	Cost per unit area of walling	Q	Extended construction		Embodied energy	Q
Wet strength	Q	Availability of raw materials		Aesthetics		Global warming potential	
Durability	Q	Complexity of manufacture		Social status / aspirations		Fuel source	
						Safety hazards in manufacture	

4 DISCUSSION OF USE

Suggestions will be given for how the HoMDReF would be used in practice. Methods for identifying requirements differ depending on how quantifiable and location-specific a given issue is. For each issue, a suggestion is provided of which methods would be most appropriate for a researcher to use to identify requirements. The potential difficulties which might be encountered are also discussed.

4.1 Technical

Technical building and material regulations exist to varying extents in LEDCs. Technical requirements should be identified to comply firstly with the legal requirements of that region, and secondly with any specific contextual

requirements as identified by the researcher. This includes future-proofing. For instance, although vertical expansion of owner-built dwellings is not common in Africa and Asia, if it is common in the region of interest then the technical requirements would be adjusted by the researcher accordingly to account for the additional strength required for taller buildings.

Regional technical requirements can be obtained from regulatory documents. If quantified requirements are not given, other regions' requirements for similar materials can be sought. For instance, several countries have standards for compressed earth blocks (Sri Lanka Standards Institution, 2009; Uganda National Bureau of Standards, 2011; Bureau of Indian Standards, 2013).

Wet strength, dry strength and durability are suggested as starting technical requirements. However, local conditions may necessitate additional issues. For instance, active seismic areas should have requirements for seismic resistance.

4.2 Economic

Issues within the economic category are strongly dependent on location as incomes, as well as costs of materials, labour and transport, vary between regions.

Cost per unit area of walling is a parameter which should be optimised in design, as the purchasing power of the urban poor is extremely limited. There are several possible approaches to estimating what the cost threshold of an innovative material should be. Ideally, the most accurate requirement would be obtained through direct consultation with owner-builders. If this is not possible, there are some approximate estimates that can be made for guidance using a desk-study methods.

With the former method, one would ask prospective owner-builders what their intended budget is, as well as asking those who have recently completed dwellings what their costs were. This will be complicated if a self-build process is used as time for material manufacture and wall construction is difficult to account for. If the cost breakdown is sufficiently detailed, one can extrapolate the average contribution of walling materials to overall construction costs. This could then be used as an upper limit for affordability.

With the latter method, one could use demographic data and personal judgement to estimate what overall cost of a house would be affordable to the urban poor in a given location. To do this, one can use a housing cost-to-income ratio (HC:Y) (Awanyo *et al.*, 2014). By using the mean urban household income for the area of interest, and specifying a HC:Y ratio, one can get an affordable household cost. This figure can be cross-checked with reported construction costs for real dwellings. Working backwards from this overall figure, one could estimate roughly the cost per square metre of walling required for a house of typical size.

As with determining cost per unit area of walling, assessing requirements for the issues of raw material availability and manufacturing complexity ideally require direct consultation with owner-builders and informal sector material producers. Requirements for both issues could vary largely between communities and regions.

4.3 Socio-cultural

Socio-cultural is arguably the category most dependent on location. The starting issues suggested here have been reported as key aspects of the housing process in sociological and ethnographic studies of the field (Wells, 1995; Wells *et al.*, 1998; Yeboah, 2005). Namely, these are to be adaptable to the sporadic nature of the construction process, and to have sufficient aesthetic merit to the owner-builders.

Home-building by the urban poor in LEDCs has been reported in general to be a lengthy process, with most dwellings completed between 1 and 5 years (Aina, 1988). However, it is known for some to take up to 15 years (Awanyo *et al.*, 2014). Without access to formal credit or mortgages (Okpala, 1992), home-builders can only buy materials with the money they have or can borrow from friends, relatives or moneylenders (Aina, 1988; Yeboah, 2005). Stockpiled materials also perform the role of personal savings, which can be sold when extra cash is needed (Yeboah, 2005).

Another characteristic is continual repair and upgrading of properties, whether to make more durable or to add extra rooms for growing families (Wells, 1995; Wekesa *et al.*, 2011; Awanyo *et al.*, 2014; Mitchell and Maccio, 2015).

The ability of materials to function within these extended processes is key. Some otherwise excellent solutions do not meet this requirement. For example, rammed earth (shown under construction in Figure 6) is a cheap and sustainable method of construction. However, its fragility during the construction process means it is only successful if completed within a short time. This issue would be a straightforward requirement for researchers to assess suitability. Direct consultation with owner-builders could identify more specific requirements within this general issue.

Aesthetics are more difficult to state as a requirement. Although aesthetic preferences are a matter of personal taste, it is expected that within a community or region, there are broad preferences in how owner-builders want their dwellings to look. In addition, it is widely documented that poor urban aspiring home-builders seek to copy the styles and materials of the urban rich whenever possible (Wells *et al.*, 1998; Yeboah, 2005), and this links to aspirations and social status.

Both the process and outcomes of identifying socio-cultural requirements will be more qualitative than for the other issue categories. A method to identify requirements should be designed so that both the minimum requirements and desirable extras that aspiring builder-owners want from their future dwellings can be recorded. This is likely to involve routine social science research tools, such as surveys and questionnaires. Significant care must be taken in method design and population sampling so that questions are not biased and answers are representative of the relevant population.



Figure 6. Rammed earth is sustainable, cheap, simple to build with, but not very popular. Is its incompatibility with the typical construction processes of the informal sector part of the explanation? Unaltered image courtesy of Daniela Ciancio, via <http://theconversation.com/cheap-tough-and-green-why-arent-more-buildings-made-of-rammed-earth-38040> Licensed under Creative Commons CC BY-ND 4.0 <http://creativecommons.org/licenses/by-nd/4.0/legalcode>

4.4 Environmental

Environmental factors include both direct and indirect impacts, which require different consideration. Included are embodied energy, global warming potential and toxicity.

The impacts of global warming are indirect, distributed and time-delayed. A quantitative benchmark value would require an estimate of how many dwellings will be built in the next 100 years, in relation to what an acceptable level of global carbon emissions are. Although this is beyond the scope of this article, such an estimate has surprisingly not been encountered so far in the literature.

In contrast to embodied energy, operational energy has been deliberately omitted. Most of the world's population growth is predicted to be in LEDCs in Africa and Asia, of which most are in year-round warm climates. Most of the urban poor do not own mechanical cooling systems due to their expense. Although this may change in the future, for this context operational energy is a far less significant source of environmental impacts than embodied energy as the improved quality of the building envelope will mean operational energy in adequate housing is unlikely to be significantly higher than in inadequate housing. In addition, this framework is designed for guiding research on walling materials. The choice of roof material can have a profound effect on the internal environment, but is largely beyond the sphere of influence of walling materials researchers.

Alongside embodied energy and carbon are a range of other impact measures. These measures include human toxicity, fresh water aquatic toxicity and

eutrophication and the relative importance of these parameters for the local and global communities needs to be assessed.

In LEDCs, the informal sector dominates materials production and construction and regulatory involvement is often non-existent. This provides opportunities for the fast adoption of innovative materials, but also risks around potential hazards in production and construction as some innovative materials may utilise source materials and processes that have increased risks for those using them. For projects on the scale of individual housing, testing of materials is limited to the knowledge of the home-builders themselves. Workers in the informal sector rarely use personal protective equipment (PPE), making them more vulnerable to production hazards than workers in the MEDCs. Without the implementation of effective regulation, there is much greater responsibility for materials researchers and designers to ensure that innovative materials will not endanger the producers, dwellers or the surrounding environment. Efforts must be taken to eliminate hazards wherever possible from the material-specific production and construction processes.

5 CONCLUSIONS

Specifying requirements for many of the issues identified as being crucial to materials research and design requires direct consultation with the given community of owner-builders to ensure local needs and aspirations are met. Some of these requirements may be difficult to quantify and the relative importance of the different aspects needs to be assessed for both the local and global communities. The local and global perspectives on aesthetics and global warming potential are likely to be very different but both viewpoints need to be considered. Whilst some information can be gained from desk studies, this is limited to a small number of issues in the technical and environmental categories. For researchers to truly serve the owner-dwellers of urban LEDC regions, there must be greater, and more targeted, direct consultation. Future research should therefore have a more collaborative, action research based agenda.

The next steps will be to follow these suggestions for a case study population. Firstly, a desk study will be done to identify certain technical and environmental requirements, and then direct consultation with an owner-builder community to identify the local issues. Once requirements have been identified, existing materials and innovative materials still under development will be assessed against these requirements to enable an improved outcome.

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