BUILDING MATERIAL SUBSTITUTES VS. TOPSOIL HARVESTING – TECHNICAL CONSIDERATIONS WITH A FOCUS ON DEVELOPING COUNTRIES

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Abstract

Due to the acceleration in processes of urbanization in developing countries, especially in Africa and Asia, large quantities of building materials are needed to construct the built environment (infrastructures and buildings). This entails the extraction of raw materials such as gravel, sand, clay, etc around the world, frequently in peri-urban areas. In particular, the mining of gravel (largely for concrete production) and the extraction of clay (brick production), e.g. by topsoil harvesting, lead land-use conflicts, undermine livelihoods and food security and degrade the environment. There is an increasing recognition that: i) more research is needed to understand and assess the impacts of this material extraction; and ii) alternatives must be explored, such as substitutes in the production of building materials.

Integrated approaches that combine impact assessments on soils and more generally on the environment with technical issues regarding the requirements of building materials and buildings are currently lacking. The paper on hand introduces the first conceptual considerations, how to potentially bridge the gap between discussions on soil and land use by geologists, environmental scientists on the one hand, and the concerns of civil engineers or town planners on the other hand. The focus lies on structuring the problem and trying to adopt a cross cutting technological perspective with the aim to open the discussion on this highly relevant topic.

1. Introduction

1.1 Problem statement

Rising populations and higher prosperity levels around the world are accompanied by a growing demand for resources. Developing countries present a particular problem due to their exploding populations and ongoing processes of urbanisation, which lead to a higher than average demand for raw materials for the construction of housing and infrastructure. In particular, it is the rural periphery of cities that suffer under the extraction of raw materials. This is where severe conflicts can arise with the interests of agriculture as well as tourism (e.g. Rahman *et al*., 2015, Weigand, 2015, Schiller & Wirth, 2015).

Studies in this field often have a narrow research focus: They address geological (Rahman *et al*., 2015) or agricultural problems (Weigand, 2015), are primarily interested in the extraction of raw materials and associated conflicts in land use, or focus on technical issues while ignoring the local supply and demand of materials (Shakir & Mohammed, 2013). The concept presented by Schiller and Wirth (2015) attempts to bring both sides together by integrating discussions on the demand for building materials with regional planning issues and the question of how to deal with the extraction of raw materials. Developed countries (EU, U.S. etc) try to address these environmental issues e.g. by green building certification systems. However, such initiatives have not yet applied to developing countries.

The paper on had outlines a research concept which attempts to fill this gap. The idea is to systematize regional-specific construction methods and technological requirements, taking into account the local supply and demand of raw materials. Starting from technical considerations, we ask what are the specific requirements regarding the quality of building materials in terms of structural safety and resistance to climatic conditions (local demand), and what potential substitute materials exist that exploit local resources in order to contribute to a reduction in the extraction of natural raw materials, i.e. the likely impact that such substitution will have on, for example, topsoil harvesting due to traditional brick constructions. A major aspect is the availability of alternative resources that can serve as potential substitutes for conventional building materials (local supply).

1.2 Literature review

1.2.1 Research into topsoil removal and food security

In many countries with high population growth and/or urbanization rates, such as Bangladesh, Vietnam and India, there is a high demand for affordable construction materials to meet the needs for new infrastructure. Despite the availability of many innovative building materials, the conventional brick is still a popular material for the construction of buildings. Clay bricks, in particular, are a widely used traditional building material. In many developing countries a common method to obtain the clay needed for brick production is by removing the topsoil (Rahman *et al*., 2015). Yet the stripping of such a fertile layer threatens soil quality and fertility as well as reducing the retention of irrigation water. Thus the removal of topsoil threatens food security and livelihoods in densely populated and rapidly urbanizing parts of South and Southeast Asia (Sebesvari *et al*., 2015). As well as degrading soil, which is one of our planet's practically non-renewable resources, large amounts of biomass (mainly firewood and rice straw) burnt in brick kilns pollute the air and account for a significant share of greenhouse gas emissions (Chen *et al*., 2010).

Kathuria & Balasubramanian (2013) state that brick kilns in India are unfortunately largely situated on fertile agricultural land, as here brick manufacturers encounter good drainage conditions and the required silty clay loam to silty clay soils. In their paper they quantify the agricultural impacts of topsoil removal by brick manufacturers on Tamil Nadu, a southern state of India. According to their findings, it is economically rational for farmers to sell soil in the short run. This decision is strengthened when the farmers' income is low and they are offered high prices for their soil. In view of the unpredictability of all agriculture activities, the option of selling soil seems particularly attractive. The proximity of the plots to the brick kilns with suitable road links and the need to level the field to provide surface irrigation by gravity flow are the other important factors that induce the farmers to sell soil. Moreover, the prices offered by the operators of the brick kilns for good quality soil have increased significantly in recent years due to increased demand and low supply. However, the opportunity cost of selling topsoil for brick production is likely to rise in the long run in view of the increasing scarcity of good quality soils for agriculture.

In Bangladesh, population growth paired with a lack of alternative building materials has boosted demand for bricks (World Bank, 2010), leading to more and more paddy fields being use for clay extraction (BUET, 2006). The spread of soil selling is partly due to a relaxation in governmental controls over the last few years (Rahman, personal communication, 2014; current Professor at Dhaka University). Brick production in Bangladesh has also been boosted by a sharp increase in demand for bricks in India, where the government has already acknowledged topsoil removal as a problem and implemented restrictions to protect soil resources (NGT 288/2013, decision of The National Green Tribunal of India). Simultaneously, India lifted the custom duty on brick imports in 2009, thereby generating lucrative opportunities in Bangladesh and encouraging the establishment of new kilns for increased exports (Thaindian News, 13.08.2009; Bangladesh News, 24.08.2009). While concentred along the Indian border and around urban centers, brick kilns can nowadays be found all over Bangladesh (World Bank, 2010).

In recent years the use of topsoil for brick production has been recognized as one factor undermining food security in densely populated and rapidly urbanizing South and Southeast Asia (Lal, 2013). Topsoil removal not only reduces land fertility while shrinking stocks of agricultural land; it also serves to lower groundwater tables (Santhosh *et al*., 2012). Despite these severe repercussions, only a small number of studies have investigated clay extraction and its impact on land productivity (e.g. Heierli and Maithel 2008) and poverty. In fact, the extent of topsoil removal around the world (and its regional distribution) is unknown; potential yield gaps are only occasionally quantified; the vulnerability of different soil types is unknown; the social and economic aspects of soil selling have not been analysed; and soil removal is not specifically considered in land degradation assessments.

More dedicated research is required to create a solid body of scientific evidence to support the establishment of monitoring programmes, recommendations and regulations, and ultimately the development of alternative solutions. One such solution is the replacement of clay by more sustainable materials such as waste (e.g. fly ash) for brick production. Without suitable substitutes for bricks, it is unlikely that soil mining can be avoided in the future. Arable land that has been degraded through soil extraction for brick production needs to be rehabilitated if crops are once again to be cultivated (Sebesvari, 2015).

1.2.2 Research into waste as a substitute material

The rapid growth in the construction industry in many developing countries has forced civil engineers to search for alternative building materials such as those derived from forms of waste (ubuntublox, 2015, ecobricks, 2015). However, such projects are mostly still at the test stage.

Research on potential material substitutes generally focusses on the use and handling of solid waste from industry and agriculture. Examples of such waste materials are sewage sludge (Liu *et al*., 2011, Cusidó & Cremades, 2012), recycled tea leaves (Demir, 2006), kraft pulp production residues (Demir *et al*., 2005), cotton and recycled waste from paper mills (Rajput *et al*., 2012, Raut *et al*., 2012) as well as rice husk ash (Raut *et al*., 2013) or PET bottles (Barman *et al.,* 2015). However, such projects are mostly at the testing stage, and the traditional means of bricks production with its hazardous repercussions has not yet been changed or replaced by a more efficient and sustainable one (Shakir & Mohammed, 2013).

1.2.3 Engineering-related research

Civil engineering studies on building materials still have a narrow focus on mechanical properties, i.e. the enhancement of material strength, performance and quality, with only minor considerations of environmental impact. The trend of research into building materials has been towards properties at the nanoscale level (Pacheco-Torgal *et al*., 2013). Alwood *et al*. (2001) have pointed out that researchers have paid too little attention to the crucial issue of materials efficiency. Only a handful of published scientific papers has addressed environmental concerns in some fashion or other, indicating that the eco-efficiency concept has not yet successfully entered this field. In addition, the Millennium Development Goals (MDGs) of the UN are generally not acknowledged in this scientific field (Pacheco-Torgal & Labrincha, 2013).

Developments in the construction industry are towards prestige projects (ever larger bridges and taller buildings, etc.) against a backdrop of high economic pressure. This is true of both developing and developed countries. Architects and civil engineers are required to meet functional and structural requirements. The choice of building materials is largely determined by these factors as well as a consideration of the overall cost. Structural engineers are only concerned with the mechanical properties of building materials and do not care about their origin in terms of which natural resource is extracted for their manufacture.

1.2.4 Interdisciplinary research

Most of the research previously undertaken in this field has focussed on the environmental impact of topsoil removal such as reduced land fertility, the consequent reduction in agricultural output and the cost of replacing the lost nutrients. This has led to suggestions for appropriate policy interventions to discourage the sale of topsoil for brick production as well as the need to find alternative sources of raw materials for bricks.

Here an integrated approach is needed, one that considers the nexus of factors associated with soil removal and the technical requirements of building materials and buildings. This paper aims to bridge this conceptual gap by proposing a line of research that encompasses both of these aspects: bringing together the more soil- and land use-oriented discussion of geologists, environmental scientists and regional planners on the one hand, and the concerns of civil engineers, architects and town planners on the other. The aim is to understand and describe the interrelationships between the different disciplines, building a solid foundation on which to develop target-oriented research and eventually derive sensible recommendations for action.

2. Scope and research methodology

The goal of the proposed research activities is to obtain greater insight into the interrelationships within the nexus of influential factors (i.e. cause-and-effect relationships) in brick production, specifically regarding soil removal and the technical requirements of building materials. The first step is to pinpoint the separate forces and factors, and to describe their relations and dependencies. Figure 1 provides an initial outline of the methodology. It is necessary to describe the chain of factors linking supply and demand in order to be able to bring together diverse disciplines and to uncover potential substitute building materials that can be used in practice.

At the centre of Figure 1 we see the interconnected forces that determine the intensity of supply and demand. Between the socially-influenced factors of urbanization and mining lie the building- and economically-oriented factors of the construction sector and producers of building materials. These latter two sectors are generally believed to show little concern for the wider environmental and social repercussions of their activities. It is precisely this problem that must be remedied so as to ensure the closer involvement of the construction sector in resolving long recognised social problems in the socio-economic, health and ecological fields.

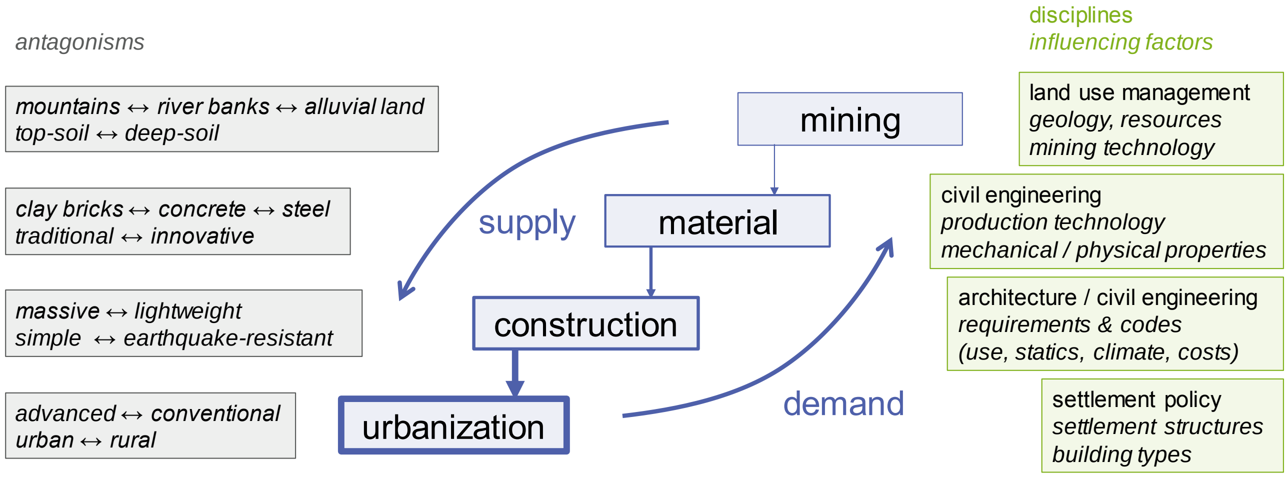

Figure 1 Sketch of cause-and-effect relationships according to the envisaged research methodology

The authors suggest that changes in the mining of raw materials, which originally were driven by wider socio-economic trends (urbanization and increasing prosperity), cannot be mediated solely by social or political actions. In fact, there are additional constraints on likely forms of construction and building materials that strongly determine the substitution potential of a range of materials. One particular focus of the paper will therefore be on a discussion of forms of construction in relation to tradition and innovation as well as structural, geographic, climatic and economic factors.

The individual driving forces will be described in more detail in the following sections along with selected examples from various developing nations. Changes to any of these forces, e.g. the transition from simple buildings to earthquake-resistant structures, can have wider implications, such as encouraging the use of alternative building materials (demand). These forces can be located in different disciplines, and are clearly influenced by diverse factors. Thus the presence of raw materials for extraction will determine the range of available building materials (supply).

Clearly the various issues cannot be sufficiently captured through a narrow research approach but require a wide-ranging analysis. The authors believe that an interdisciplinary approach must therefore be adopted.

3. Driving forces (demand)

3.1 Urbanization and prosperity

At the social level it is possible to discern two main forces driving the demand for building materials, particularly in developing countries. The first of these is a rapidly increasing population, primarily in cities, contributing to the ongoing process of urbanization. The other is growing prosperity and the accompanying desire to adopt a more western style of life. Both of these developments, which are illustrated below in the cases of Bangladesh, Pakistan and Vietnam, serve to boost the demand for building materials, although in different ways.

In Bangladesh, for example, the process of urbanization is just getting underway, so that the vast majority of the population still live in rural areas (Table 1). In Pakistan, in contrast, already approx. 40% of the population live in cities (*Figure 2*), a figure that will increase to over 50% over the next half-century.

Table 1 Household and Population acc. to Bangladesh Population and Housing Census 2011

	Absolute number			Percentage	
Household and Population	Total	Rural	Urban	Rural	Urban
Total Households	3,707,047	3,114,437	592,610	87%	13%
Total Population	15,386,663	12,953,935	2,432,728	88%	12%

In Vietnam it is forecast that the population will increase by 40% in the four decades to 2055. This corresponds to an annual rise of around 1% (*Figure 3*). This increase will largely be concentrated in urban areas, for which an increase of 177% is predicted over four decades (4.4% annually). Over the same period the rural population is forecast to decrease. As a clear indication of increasing urbanization, it is predicted that in only 25 years the majority of the Vietnamese population will be living in cities. An increasing population in itself will stimulate the building sector due to the rising demand for housing and infrastructure, which will consequently drive demand for building materials.

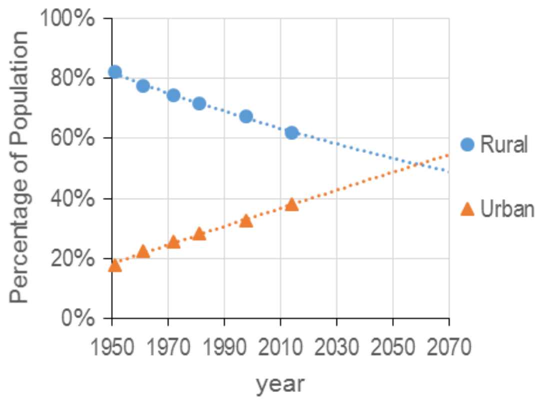

Figure 2 Trends in Pakistan's population distribution (data: Pakistan Bureau of Statistics (1998), The World Bank (2015))

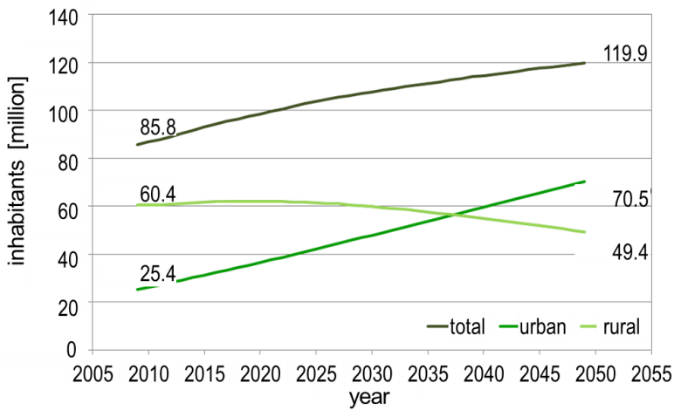

Figure 3 Population projections for Vietnam (data: Vietnam General Statistics Office (2011), p. 33)

Increasing prosperity can also be illustrated using the example of Vietnam. A drop in the number of persons in the average household indicates a shift in the style of life (Figure 4) towards more living space per person. Furthermore, rising prosperity boosts the expectation of higher standards in building construction, which drives the market for high quality building materials.

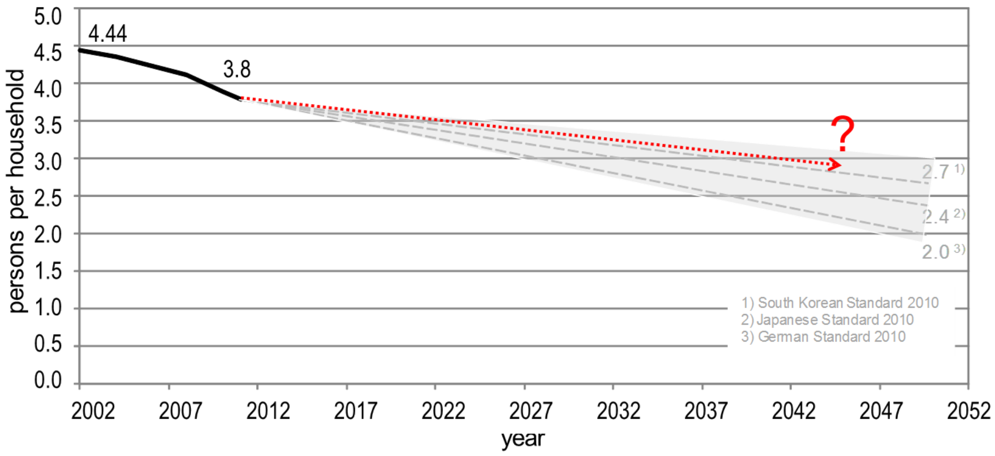

Figure 4 Population forecasts for Vietnam (data: Vietnam General Statistics Office (2011), p. 33)

3.2 Construction types

3.2.1 Trends in building materials for construction

The shift in types of construction will be examined more closely in the following using the examples of Bangladesh and India. Clearly, such changes influence the demand for building materials: alongside a general increase in demand (with rising population) there can be a shift in the relative demands for various materials. Table 2 shows how the typical forms of construction have changed in the two countries over the past years.

Alongside the process of urbanization, which in India reflects population growth that between 2001 and 2011 was twice as high in the cities as in rural areas, there is a clear trend towards more robust building materials. However, this trend shows regional differences between urban and rural areas. Whereas stones are preferred for the construction of floors in cities, burnt bricks are gaining favour in rural areas. In Bangladesh solid materials such as brick and cement (masonry) are increasingly replacing mud as the material of choice.

Table 2 Trends in construction materials for Indian and Bangladeshi housing (sources: Census of India (2001, 2011), Bangladesh Population and Housing Census (2011))

	India change from 2001 to 2011			Bangladesh change from 1991 to…	
Construction Material	Total	Rural	Urban	2004	2011
Total number of census houses	+22%	+16%	+37%		
Floor material:					
Mud	+1%	+2%	-6%	-	-19.8%
Wood/bamboo	+13%	+15%	+5%	-	-0.5%
Burnt brick	+25%	+33%	+11%	-	+18.6%
Stone	+65%	+51%	+83%		
Cement	+41%	+50%	+31%		
Mosaic/floor tiles	+74%	+85%	+71%	-	+1.7%
Any other material	+49%	+16%	+79%	-	-
Wall material:					
Straw/bamboo/polythene/plastic/canvas				-11.8%	-42.3%
Grass/thatch/bamboo etc.	+17%	+19%	-2%		
Plastic/polythene	+52%	+60%	+37%		
Mud/unburnt brick	-10%	-11%	+2%	-2.7%	-6.0%
Tin (CI sheet)				+23.0%	+40.6%
Wood	-13%	-10%	-22%	-11.5%	-11.4%
Stone	+71%	+41%	+188%		
G.I./metal/asbestos sheets	+17%	+45%	-5%		
Burnt brick	+31%	+33%	+28%	+2.9 %	+18.1%
Concrete	+68%	+64%	+70%		
Other materials	+211%	+210%	+213%	-	+1.0%
	India change from 2001 to 2011			Bangladesh change from 1991 to…	
Construction Material	Total	Rural	Urban	2004	2011

Roof material:					
Straw/bamboo/polythene/plastic/canvas				-18.8 %	-42.9%
Grass/thatch/bamboo/wood/mud etc.	-12%	-12%	-7%		
Plastic/polythene	+77%	+118%	+22%		
Tin (CI sheet)				+18.4 %	+34.4%
Tally				-	+1.5%
Hand-made tiles	-47%	-45%	-57%		
Mass-produced tiles	+841%	+750%	+1,324%		
Burnt brick/cement	-34%	-20%	-54%	-0.5 %	+6.1%
Stone/Slate	+92%	+93%	+90%		
G.I./metal/asbestos sheets	+193%	+189%	+204%		
Concrete	+71%	+82%	+64%		
Other materials	-21%	-28%	-2%	+0.5 %	+0.4%

Stones are increasingly being used for the construction of walls in India's cities, whereas in rural areas simpler materials such as plastic or polythene or even galvanised iron (G.I.), metal or asbestos sheets are more common. In both areas concrete is gaining in popularity. In Bangladesh simple materials such as straw, bamboo, polythene, plastic or canvas are being replaced by tin sheets, bricks and cement in the construction of walls. Regarding roof construction, in India we find a growth in the use of industrially produced materials. Thus the use of hand-made tiles is decreasing at the same time as demand for mass-produced tiles has hugely grown. This is particularly evident in urban areas. In Bangladesh there has also been a clear fall in the use of natural and plastic materials in favour of more robust tin roofing.

3.2.2 Typical forms of construction

In the centres of large cities and conurbations, a wide range of construction methods can already be found, ranging from lightweight steel, lightweight concrete and hybrid building systems to heavy concrete panels and building blocks, especially for social infrastructure and office buildings. Despite the trend towards innovative construction methods, traditional methods are still much preferred, so that traditional materials still make up the vast bulk of structural elements.

In Pakistan, for example, 62.3% of the built environment is constructed as brick masonry. Buildings of this type are common in rural, suburban and urban areas. Brick masonry is widely used in the most populated states of Punjab and Sindh (east and south-south east) (EERI & IAEE, 2013). The load-bearing structure is generally in the form of brick masonry walls constructed using either sun-dried or fired bricks with mud or cement as mortar. Brick masonry buildings can range from single storey houses common to rural areas to three-storey buildings more frequently found in urban areas.

The foundations, which extend beyond the walls, are generally constructed using brick masonry with cement sand mortar. From plinth level, the walls are constructed of either mud mortar or cement sand mortar. Various types of materials are used for the roofing, which rests directly on the walls without any connections. Construction of this type of housing takes place in stages over many years. Typically, the larger end form of the building does not correspond to the original design.

Due to the rapid urbanization that Pakistan has undergone over the recent past, builders have been forced to turn to reinforced concrete to construct both commercial and residential buildings. Such buildings can be most frequently found in the wealthier urban centres of major cities (EERI & IAEE, 2010) in view of the better economic conditions, higher population and high land values. While reinforced concrete is also used to construct buildings in city suburbs, here the primary function is to accommodate commercial facilities. Such buildings are usually not taller than 3 to 4 stories. The ratio of reinforced-concrete buildings in suburban areas is only 1 to 2% of the total building stock. RC buildings are typically moment-resisting frame constructions with infill walls, designed to be earthquake resistant. The infills for the frames are usually of brick and block masonry.

3.2.3 Structural and building-technology requirements

Structural and other building-technical requirements are determined by regulations such as building codes (e.g. for earthquake resistance) and other standards (e.g. thermal insulation) as well as climatic conditions. Security against the effects of seismic activity is in many countries one of the main structural requirements of buildings. The various buildings codes that most developing countries have adopted are largely based on the American ACI Code or British standards.

In Pakistan, for example, the code governing the most typical forms of mass construction is limited to ensuring the structural integrity of reinforced concrete constructions. There are no design or structural guidelines governing brick masonry buildings; local masons rely on their experience, while engineers or architects are generally not involved. This type of construction is non-engineered and not regulated by land-use controls. Thus building permits are not required to construct masonry houses and they are not addressed by the building codes/standards of the country. Buildings constructed from masonry were badly damaged by Pakistan's recent earthquakes due to inherent weaknesses in the load-bearing structure and the use of poor quality materials. In regions that are regarded as earthquake prone, engineers prefer to design steel-frame or reinforced concrete structures, as brick buildings offer little resistance to such seismic forces.

The Uniform Building Code (UBC-97) regulates the type of permissible construction for each seismic zone. While ordinary RC moment-resisting frame (OMRF) buildings are considered adequate for Seismic Zone 1, civil engineers have to construct Intermediate RC moment-resisting frames (IMRF) in Zone 2 (as a minimum measure) and Special RC moment-resting frames (SMRF) in Zones 3 and 4. These stipulations become increasingly stringent for higher zones. For example, code ACI-318 has specific provisions regarding size of column and beams, lap length and developments of reinforcement, joints of beams and columns for SMRF, in addition to those stipulated for IMRF; it also requires that the flexural strength of columns be greater than beams. Further, the code regulates the static load-bearing behaviour of the brick infill walls by designing them as shear walls. The end result is to set minimum wall thicknesses and minimum strength requirements. However, the particular level of earthquake resistance applying to a building will largely depend on the budget allocated to the project and, to some extent, on the building's importance. Thus, typical low- to mid-rise buildings are generally OMRF, while taller buildings with a higher level of importance are designed as SMRF or dual systems.

A further major consideration is resistance to climatic conditions. Particularly in very hot regions, it is essential to use heat-insulating building materials with a large heat storage capacity. This requirement is met by all heavy materials such as concrete or brick walls as the traditional form of construction. Because brick masonry has excellent physical properties regarding heat insulation, it is a natural choice for most people in Pakistan. In areas where temperatures can often soar above 38-40°C, accompanied by strong, dry gusts of air, brick walls can ensure that the interiors of homes stay relatively cool and well-ventilated. Bricks trap heat during the daytime, and slowly dissipate it at night as temperatures fall. Similarly, they also protect against extreme cold in areas where temperatures can fall below zero.

In theory, wooden structures can meet these requirements while making use of a naturally replenishing raw material. However, climatic conditions in Pakistan favour the proliferation of termites, whose activities can quickly weaken and destroy wooden buildings. Thus wooden structures are generally avoided.

3.3 Building materials

Depending on the calculation of the structural specifications of a building, planning engineers require building materials with particular characteristics in regard to strength, density or ductility. The construction of SMRF concrete buildings, for instance, needs high quality cement and aggregates (sand and gravel or crushed rock) for the concrete as well as large amounts of standardised ductile steel as reinforcement. Slightly lower requirements are demanded of smaller concrete buildings that use less steel and concrete. The strength of standard concrete depends on the quality of the aggregates. High-strength concrete requires good quality cement and a precisely designed grading curve (mix of aggregates). Further, some types of sand and gravel are not suitable for use in reinforced concrete as they can induce undesirable chemical reactions that degrade quality. For example, chlorides in desert sand can corrode steel reinforcements while silicic acid in river gravel causes a harmful alkali-silica reaction (ASR).

Today large amounts of clay soils are consumed to supply bricks for the huge number of buildings still constructed with masonry. The specification for the clay content in the soil is solely based on the required quality of the burnt brick. Thus the soil should contain a minimum proportion of clay and as little organic matter as possible as these reduce the final strength through oxidisation during the sintering process of the bricks. From this point of view, topsoil is a poor choice as raw material for brick production.

3.4 Mining of raw materials

The end users of a building material normally do not specify where raw materials be sourced. For them the only decisive factors are the quality and the price of the final product. Yet in view of the fact that the distance between the building site and the location where a material is extracted significantly determines the price (due to high transport costs of the heavy mineral materials), mining takes often place nearby fast-growing cities. Aggregates for concrete production are mainly taken from riverbanks, gravel pits and, increasingly, from the seabed. The raw material for bricks may be extracted from clay soils, which can be found in various soil layers in alluvial lands.

4. Driving forces (supply)

The availability of raw materials varies greatly from region to region, and thus is a major factor in the type of construction favoured in each country. This can be illustrated using the example of Bangladesh.

Bangladesh can be divided into three physiographic units: Around 80% of land is made up of recently formed floodplains, while 8% is Pleistocene terraces and 12% Tertiary hills (Rahman *et al*., 2015). Due to these geological conditions, the country lacks the stone aggregates such as sand and gravel needed for concrete production (especially for ceilings, which are difficult to construct using other materials). The country's small hill ranges provide little stone chip to be used as aggregates. Therefore, it is necessary either to import aggregates or to produce them from other available raw materials. Due to the high cost of importing aggregates, the common solution in Bangladesh is break bricks manually or by using a brick crusher to obtain an alterative coarse aggregate for concrete.

The geology of Bangladesh offers different types of soils that can be used to extract material for brick production. These are alluvial soils, topsoils, silty clay loam and silty clay soils. While topsoil is only one source, it is a commonly exploited due to the prevalence of simply hand-mining techniques. Deep soils, which consume less arable land, are also an option. However, the extraction of deep soils requires mechanical equipment available only to large mining companies.

The supply of building materials produced from secondary raw materials such as building rubble and other forms of waste (e.g. plastic bottles and bags, packing materials, polystyrene) cannot be sufficiently quantified at the present time.

5. Technical considerations on the potential for building material substitutes

Cost-efficient building material for the construction industry usually takes the form of cheap, locally-sourced raw materials. The use of burnt bricks on a massive scale can be reduced in certain areas by a change in construction methods. However, substitution is limited by the need to maintain structural integrity and other physical parameters. These are basically determined by the loads a building is expected to bear and the environmental influences it must resist.

The most severe test of a building's load-bearing structure is certainly an earthquake, as here the structure must resist not merely vertical, static loads but also lateral, dynamic loading. Buildings newly constructed in earthquake-prone regions must obey existing standards and guidelines in order to withstand such forces. South Asia is one such region with many seismic zones. Brick buildings are particularly susceptible to earthquake damage as they are little able to resist lateral loads. This has motivated countries such as Pakistan to reconsider their building codes: tall buildings are now constructed with reinforced concrete frames. However, as the necessary raw materials are lacking to produce large amounts of concrete, these frames are still infilled with masonry panels.

The question now arises: To what extent can materials be substituted? Building planners already attempt to optimise the use of material in their structural calculations (when building codes apply) in order to keep down construction costs. Thus it can be expected that a building's load-bearing capacity will not be designed with much redundancy. Regarding the substitution potential of load-bearing elements, three questions must be answered regarding structural safety:

1) Earthquake-prone regions (seismic zones 3 & 4):
   UBC-97 requires that special moment-resisting frames be used to construct buildings, i.e. steel or reinforced concrete frames, in which the infill panels function as load-bearing shear walls. Possible substitute materials for bricks are concrete blocks, reinforced concrete or alternative steel constructions that provide the load-bearing function.
2) Regions with low or medium earthquake activity (seismic zones 1 & 2):
   Buildings in these regions also have to be constructed with a moment-resisting frame. Fewer load-bearing shear walls are specified than in zones 3 & 4. This offers a higher potential for material substitution while preserving structural safety. Additional safety aspects, however, apply to the exterior walls, thus limiting the substitution potential.
3) Regions with no earthquake activity:
   Here few restrictions apply to the substitution of materials for brick walls. Thus solid bricks in load-bearing walls can be replaced by hollow bricks. Another option is to use breezeblocks or sand-lime bricks. In buildings with only a few storeys, it is also possible to use porous or lightweight concrete, or indeed diverse innovative waste materials (e.g. ecobrick, ubuntublox) without compromising stability.

From the perspective of structural safety, it should be pointed out that the properties of substitute materials for masonry walls such as ecobricks or ubuntublox currently do no meet valid standards or guidelines. In rural areas where building codes generally do not apply, a substitution potential exists. However, it should be added that the strength of these building materials are only suitable for the construction of simple one-storey buildings.

No structural-safety requirements apply to non load-bearing elements such as masonry dividing walls. Non load-bearing interior walls only serving to enclose rooms can be replaced by light dividing walls made of materials such as plasterboard or derived timber products. Substitutes made from simple waste materials can also be used. However, additional technical aspects must be considered in the case of (non load-bearing) exterior walls. These are, for example, heat and cold insulation with simultaneous water resistance, characteristics that not every building material displays. Hence, strongly water-absorbing materials cannot be used in wet regions, and lightweight materials offer little protection against summer heat as they have insufficient thermal storage.

It is not always possible to replace bricks as a building material. Availability of alternatives is generally determined by the local supply of raw materials, such as in Bangladesh, where brick chips are until today the most widely used aggregate for concrete. A substitute for split brick aggregates in concrete is difficult if not impossible to find due to the lack of alternative aggregates. One possible substitute is to use recycled masonry to produce lightweight expanded clay aggregates for concrete. However, an important limiting factor here is the presence of gypsum in the masonry waste, which can serve to weaken the concrete. Some researchers suggest, for example, using fly-ash from thermal power plants to produce a kind of concrete brick (e.g. Flyash Bricks, 2012), which is certainly a viable technical solution.

In principle, it is possible to substitute topsoils with deeper layers of soil. The quality of the resulting brick may even improve due to a lower proportion of organic material in such soil. Burnt bricks from deep soil can achieve higher strengths than standard bricks. This means that an equivalent strength can be achieved with less raw material. Hence the use of deep soil not only contributes to the substitution of topsoil but also to a reduction in the consumption of natural resources.

6. Conclusion and Further Research

Building activity is governed by a mix of innovation and tradition. The research concept presented in this paper should push-start a discussion on possible research methodologies, i.e. integrated approaches which combine impact assessments on raw material extractions on the environment with technical issues regarding the requirements of building materials and buildings. The first lines of thought concerning this problem reflected upon have revealed opportunities as well as limits to the substitution of traditional masonry in buildings while taking account of the local supply and demand for raw materials as well as technical requirements, in particular the need to produce safe load-bearing structures.

The desire of people in developing nations to secure a prosperous life for themselves, which includes the wish for high quality housing along the lines of developed countries, restricts the options of replacing traditional building materials with simple or inferior materials. Presumably, such technical innovations as ecobricks or ubuntu-blocks that make use of waste materials conflict with this aim of better living standards (problem of acceptance). Instead, these can usefully serve members of the poorest sections of society who are forced to make use of simple building materials and construction methods. Waste bricks alone will certainly not solve the serious global problem of resource scarcity.

From a technical perspective, it is largely the requirements of structural safety and resistance to climatic influence that determine the substitution of topsoil with alternative raw materials. The structural requirements of buildings vary greatly depending on the local level of seismic activity. The higher these requirements, the more limited the permissible forms of construction, and thus the potential for substituting masonry walls.

Also the requirement of resisting climatic influence can mean that certain raw materials are not suited as substitutes. This was discussed in relation to the susceptibility of wood to termite attack. Similarly, lightweight constructions are not good solutions in hot regions, at least for the exterior walls of buildings, and can also serve to compound other environmental problems (for example, high energy consumption for air-conditioning).

Even if a technically feasible substitute material exists, a limiting factor can be the supply of raw materials. Such supply, which can vary greatly from region to region, depends not only on local resources but also on the availability of suitable extraction equipment. Clearly, the supply of building material determines the types of possible construction. In a country such as Bangladesh, where clay soil is virtually the only natural raw material for construction, structures made of burnt bricks will dominate the built environment as well as building activities for the foreseeable future. Furthermore, the lack of aggregate material impedes the trend towards more reinforced concrete structures. In this context it is also important to investigate whether the import of raw materials such as gravel and sand is a feasible option for the substitution of local raw materials (clay soils), both in regard to the economic and ecological impact.

The availability of extraction technologies and associated costs is the primary factor in determining the type of raw material used. As long as topsoil mining is easier and cheaper than mining other kinds of soil (e.g. deep soil), the manufacturers of building materials will continue to supply burnt bricks made from this valuable resource.

Summarising, we can say that in view of the many regional influential factors, no general conclusions can be drawn regarding the nexus of diverse driving forces behind the problem of topsoil harvesting. Instead, more detailed regional studies are required.

The extraction of topsoil in a number of Asian countries strongly impairs current and future agricultural productivity as well as the functioning of irrigation schemes, thereby endangering livelihoods and food security. Today there is a lack of detailed information on the extent of topsoil harvesting around the world as well as how this impacts the quality and productivity of farmland and indeed the livelihoods that depend on these. Research is therefore needed to quantify the availability of secondary materials as well as to examine the possible use of recycled (waste) products or other potential substitutes in different types of construction and in diverse forms of settlement, while meeting a range of load-bearing and climatic requirements. Such quantification of feasible substitutes will form the basis for the development of management options or recommendations for action and, not least, determine how well these solutions can be transferred around the world. To sum up, further research will be necessary in the future, especially in collaboration between researchers of different disciplines by using interdisciplinary approaches to overcome the outlined problem.

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