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Developing a Sustainability Framework for the Second Life of Palm Oil Clinker

Chee-Ming Chan and Alina Shamsuddin

Abstract* — Palm oil constitutes a main agricultural commodity for the country, therefore the large quantity of palm oil clinker (POC) produced as a waste at the refineries is not unexpected. Upon the discovery of the rock-like but porous POC as being strong and robust enough as substitutes of aggregates, they have since become popular alternative materials in road pavement and concrete. However, POC is also potentially viable in other civil engineering applications for a second life, and this includes brick-making, soft soil stabilisation and greywater filtering. (i) Powdered POC was found to contribute to greater strength gain than cement in baked clay bricks, promising a cheaper yet more environmental-friendly building material. (ii) Admixed with soft clay soil, ground POC was found to effectively dry and strengthen the originally weak soil through induced cementation, similar to those achieved by using commercial binders, like cement and lime. (iii) Crushed POC replacing conventional sand in a greywater filter for domestic kitchen sink discharge showed evidence of effective cleansing, where the filtered water met the requirements of Standard B effluent suitable for release into public waterways. While the experimental results strongly suggest the huge potential of restoring POC to a useful second life in various civil engineering applications, encompassing the 'rebirth' from cradle-to-grave in a sustainable framework is essential as assessment and justification for its continued viability. By putting the materials and methods in a birth-to-death cycle, from production, application to end-of-life management, the relevant causes and impact are reviewed and examined. The inter-related societal, economic and environmental aspects are then incorporated in a holistic 2-pronged life cycle and functionality analysis. In short, the sustainability framework features not only technical soundness of the POC's second life, but considers in detail the other consequential and accompanying factors throughout the 'second' life cycle of POC.

***Keywords* — POC, recycling, sustainability, soil, greywater.**

I. Introduction

One of the singularly pressing issues faced by all civil engineering practitioners worldwide is striking an acceptable balance between 'destruction' and 'protection'. The former is notoriously (but not necessarily correctly) associated with the clearing of forests, defacing of natural environment, mass extraction of raw materials, right down to the construction stage with various forms of pollutions and disturbances. As for the latter, it is equally arguable that infrastructure needs to be built, improved and maintained for the convenience, comfort as well as survival of mankind. It is beyond any doubt that without these physical developments, a nation cannot expect to run its functions properly, let alone to bring forth significant progress economically or socially.

As necessity breeds creativity and innovation, construction materials and methods have undergone major improvement over the years. Sustainable construction requires that while meeting the economical, social and cultural needs of today, the future generation is not deprived of the necessary resources due to excessive depletion or degradation [1]. These efforts are generally driven towards enhancing the 'green' values, i.e. eco- friendly, economical, enterprising and sustainable. Low carbon emission and more energy-efficient machinery, for instance, are widely mobilised these days on construction sites. The materials, on the other hand, are now manufactured with ingredients which are either sourced in 'environmentally-responsible' and 'legally correct' manner, or retrieved from some waste or by-products generated in one industry or another. There is also a parallel rise in the research of material recycling and energy conservation to meet the industry's demands [2].

Malaysia, being an essentially agro-based country, inevitably produces large quantities of agricultural wastes. Unfortunately, the agro-based industries worldwide are not always effectively and adequately managing or utilizing these wastes [3]. Coupled with the need to preserve the supply and use of traditional building materials, which are facing depleting resources and rising costs, the civil engineering community is obliged to seek alternative ingredients for the production of modern day building materials. This is not new, as already proposed by Abang Abdullah [4] almost 4 decades ago. Muntohar [5] summarised it well, that escalating environmental issues are stimulating interest and driving efforts to use waste or by-products as alternative construction materials. Indeed, for an all-encompassing and pervasive engineering field, such interest and effort should be propelled towards wider civil engineering applications as a whole.

It is against this background that this paper was written, to highlight the potential reuse of an abundant agricultural waste in Malaysia, i.e. palm oil clinker (POC), in civil engineering applications beyond that of concrete and pavement. Malaysia was the largest producer of palm oil, contributing about 50.9 % of total production in the world [6], until 2007 when Indonesia surpassed Malaysia to be the top producer. Nonetheless the oil palm industry and affiliated trades remain a backbone of the nation's economy, and an important thrust for rural socio-economy development. It is therefore imaginable, the copious amount of POC available for disposal, or better, a second life.

II. Material and Methods

A. Palm Oil Clinker (POC)

Fig.1. Palm oil clinker (POC)

POC is a by-product of the burning of discarded husks, fibres and shells of the harvested oil palm fruit. These wastes are commonly used as fuel material for heating the boilers in a palm oil mill. According to Tay [7], as much as 1/5 by weight of ash and other residues, including clinker, are produced in the burning process. While the beneficial chemical properties of the ashes (i.e. POFA, palm oil fuel ash) have long been discovered and harnessed, the seemingly inert clinker has remained largely an untreated waste transported to landfills or other disposal sites, bringing with it the risk of contamination [8]. On the other hand, it was reported by Kamaruddin [9] that POC was first utilized as lightweight aggregates in Malaysia as far back as in the 70's. More recent applications of POC as a lightweight substitute for aggregates and gravels in concrete can be found in [10, 11 & 12]. The POC (Fig. 1) used in the present study was of the same batch, as supplied by a local palm oil mill in Kahang, Johor. The physical and chemical properties can be referred to in Table 1.

Table 1 Physical [13] and chemical [14] properties of POC

Physical properties	Fine	Coarse
Specific gravity (saturated dry surface)	2.17	2.60
Moisture content (%)	0.08	0.05
Water adsorption (%)	4.65	1.79
Bulk density (kg/m^3)	863.65	1815.23
Fineness modulus	2.84	2.65

Element		Concentration (%)
Silica dioxide	SiO_2	81.8
Feric oxide	Fe_2O_3	5.18
Potassium	K_2O	4.66
Aluminium oxide	Al_2O_3	3.5
Calcium oxide	CaO	2.3
Magnesium oxide	MgO	1.24
Phosphorus pentoxide	P_2O_5	0.76
Titanium dioxide	TiO_2	0.17
Natrium oxide	Na_2O	0.14

B. Soft Clay (RECESS Clay)

The clay used in the brick and stabilised soil studies was collected from the test site of RECESS (Research Centre for Soft Soils), hence named "RECESS clay", in disturbed bulk samples at a depth of approximately 2 m (Fig. 2). The uniform clay deposit had an average water content of 84%, and contained some organic materials like grass blades, roots and small fragments of decaying wood. Physical properties of the clay are as listed in Table 2.

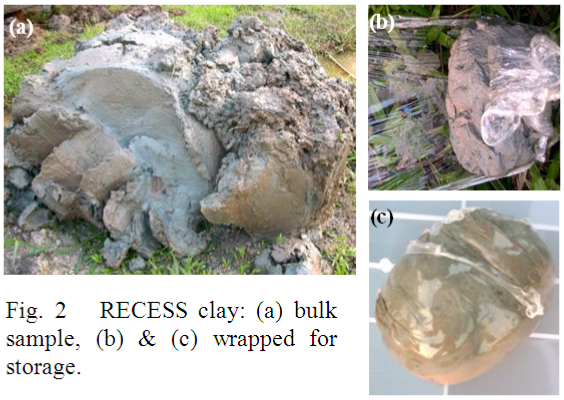

Fig. 2 RECESS clay: (a) bulk sample, (b) & (c) wrapped for storage.

Table 2 Physical properties of the RECESS clay

Properties		
Liquid limit, LL	0.68	
Plastic limit, PL	0.32	
Plasticity Index, PI	0.36	
Moisture content	84.19 %	
Grain size distribution (%)	*Silt*	89.20
	Clay	10.23
	Sand	0.57
pH	3.32	
Colour	Light grey	
Specific gravity, G_s	2.62	

III. Second Lives of Palm Oil Clinker (POC)

A. POC-Clay Bricks

Approximately half-sized bricks (100 mm x 50 mm x 30 mm, where a conventional standard brick size is 225 mm x 113 mm x 75 mm; see [15]) were made with a mixture of the RECESS clay and fine POC, then left to cure in either baked or non-baked conditions. Reference specimens of clay only and clay-cement mixtures were also included in the test series. 5 specimens each of the same mixture were subjected to either to 200ºC oven drying (non-baked, "NB") or 800ºC firing in a furnace (baked, "B").

Compressive strength test was next conducted in accordance with BS3921: 1985 [16], at a constant loading rate of 15 N/mm^2 applied on the bed face (100 mm x 50 mm) of the brick specimens. The test was terminated immediately after the peak strength was attained. Fig. 3 shows the strength - deformation curves of all the specimens. Baking was clearly necessary to provide

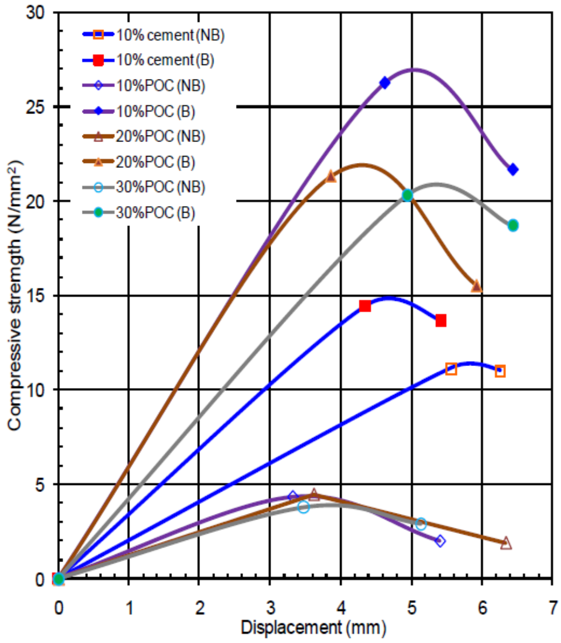

Fig.3. Compression curves of the bricks

compressive resistance to the clay-POC mixtures, as shown by the markedly low strengths of the NB specimens. Baked at the same dosage of 10 %, the POC-clay specimen had almost twice the strength of the cement-added one. However 10 % POC addition appeared to be the optimum dosage, for further increase in POC addition actually reduced the strength. Referring to the Malaysian Standards for bricks, MS76: 1972 [17], a brick with compressive strength ≥ 70 N/mm2 qualifies for the highest category of Class A Engineering Brick. The British Standards, BS 3921: 1985 [16], stipulates a less stringent ≥ 50 N/mm2 as the minimum strength requirement for the same category. While none of the specimens made the class, all fulfilled the minimum compressive strength of 5.2 N/mm2 for conventional bricks.

B. POC Soil Stabiliser

The experiment with POC as a potential soft soil stabiliser stemmed from the cementatious properties inherent of its ash (POFA). It is suggestive that finely ground clinker (from the same parent materials) could effectively enhance the strength and stiffness of soft, weak soils too. Ground to powder form (particles < 425 m), POC was admixed with the RECESS clay at a range of 5-15 %. The control specimen was prepared with 5 % cement addition. The cylindrical specimens measured 38 mm in diameter and 76 mm in height, and were cured in a 20oC, moist, airtight environment for up to 28 days. The monitoring tool adopted in this study was the non-destructive bender element shear wave velocity (vs) test system. The test induced a transient perturbation on the specimen via shear waves and from the travel time captured, a simple formula was used to estimate the small strain shear stiffness, a parameter established to relate closely to strength in stabilised materials [18]. At intervals of 3, 7, 14 and 28 days, changes in stiffness (hence strength) of the specimens were examined with the test system. As the test was non-destructive, the same specimens were repeatedly tested, consequently eliminating errors arising from the non-uniformity of specimens.

In Fig. 4, v_s is plotted against the age of specimen (A). Note that the clay only specimen remained unchanged throughout the test period. Added with 5 % POC, a significant rise in v_s beyond 28 days can be observed, though the rate of increment clearly diminished with the specimen's age. Specimens with POC dosages of 10 % and above showed remarkable improvement, which could well extend into longer periods. Besides, 10 % POC addition alone was sufficient to achieve the same improvement of the soil as 5 % cement, a positive sign of the stabilising potential of POC. Admixed with 15 % POC, the property enhancing effect surpassed that of 5 % cement addition by over 20 % after 28 days. Moreover, POC was apparently more reactive in treating the clay, judging from the steeper climb of the v_s-A curve of specimen 15 % POC.

On the other hand, it is interesting to see that the cementatious properties of POC seemed to be subdued when blended with cement (C-POC) in the clay soil, as depicted by the closely positioned plots of the respective specimens in Fig. 4. The full explanation is pending further research, but 2 hypotheses were suggested: (1) there was inadequate moisture available for the hydration of both materials; (2) complex chemical reactions took place and resulted in an imperfect formation of cementatious bonds. Regression lines plotted through the C-POC and POC treated specimens intersect at approximately A = 25 days, after which the latter appears to undergo a continued increase while the former reaches a plateau.

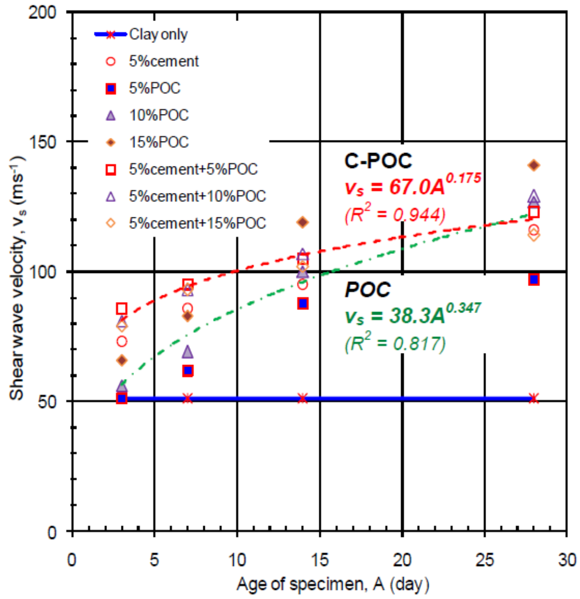

Fig.4. Shear wave velocity (vs) – age of specimens (A).

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C. POC Greywater Filter

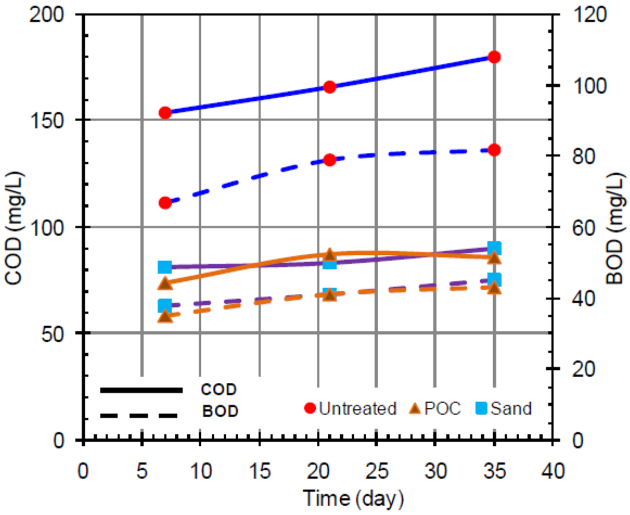

Fig.5. Chemical (COD) and biochemical (BOD) oxygen demands against time

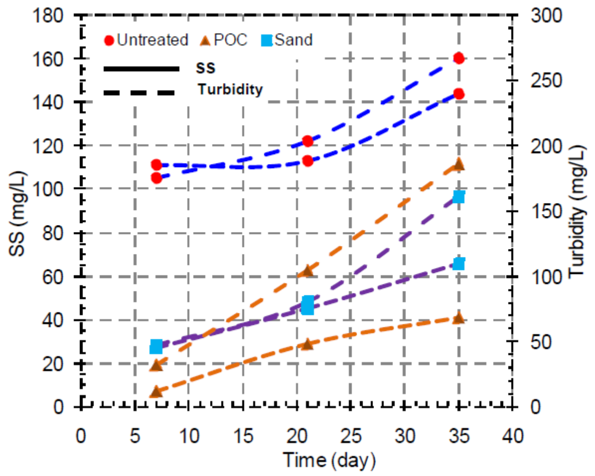

Fig.6. Suspended solids (SS) and turbidity levels against time

All used water discharged from a house, except from the toilet, are termed as 'greywater'. It can be from the kitchen, bathroom, washing machines and other washing facilities in the house, therefore contains impurities and microorganisms derived from everyday household and personal cleaning activities. In conserving water, greywater can be reused for non-potable purposes, such as landscape or agricultural irrigation, with basic treatment prior to dispensing. The study described here was targeted at the filtration stage of kitchen greywater, where crushed POC was used as a substitute for sand in a conventional multi-tiered filter. As March et al. [19] pointed out, longer storage time will cause the quality of greywater to deteriorate with increased levels of suspended solids, nutrients and pathogens. A simple filter system can serve as an economical and quick first-stage treatment for kitchen greywater before the more elaborate disinfection process, if necessary.

Collected from a single kitchen sink, the greywater was filtered through conventional sand and POC filters respectively. Water quality check was then conducted on the filtered water at intervals of 1, 2 and 5 weeks. In Fig. 5, the chemical (COD) and biochemical (BOD) oxygen demands are plotted against time. COD is a chemical measure of the organic strength of water samples, while BOD indicates the quantity of oxygen used in the aerobic oxidation of organic matter in a water sample by the microorganisms present at 20$_o$C. The performance of POC equaled that of sand as the parameters were markedly reduced in both cases. This shows the effectiveness of POC in entrapping microorganisms in the greywater, leaving a cleaner output which can be potentially stored for longer. This will consequently exert less demand on the disinfection mechanism too.

The suspended solids (SS) and turbidity versus time plots are shown in Fig. 6. As more non-dissolvable matters remain in the water, SS level will rise in parallel with the cloudiness, defined as turbidity. POC appeared to be marginally less effective than sand in removing the water's murkiness. This is attributed to the larger particle size of POC used in the filter, which was inevitably more susceptible to clogging as the microbes grew and coated the particle surfaces. The resulting smaller voids impeded filtering of the suspended matters. However, smaller POC particles are likely to resolve this problem.

IV. Sustainability Framework

Considering that POC is a waste material destined for disposal in landfills or reused as a gravel or aggregate substitute in concrete and pavement, the second lives presented above highlighted the potential reutilisation in other areas, further enhancing the material's sustainable values. A sustainability framework is therefore derived to conduct a preliminary evaluation of the actual 'green' benefits, which could be referred to as a supporting document in encouraging manufacturers and builders alike to adopt the material by reintroduction to the reuse cycle.

A. Issues and Challenges

As mentioned earlier, due to its rock-like nature, POC is generally regarded as a good substitute for aggregates and gravels. Its other propitious properties remain unexplored, hence little is understood of the above presented potentials. There is probably a relatively low level of awareness of the material among practitioners, and little has been done to promote its potential second lives. Moreover, variations in the physical and chemical properties of the POC are undeniably a hindrance to tapping its full potential, as such differences could incur quality control and safety problems. There also appears to be a gap in communication among those involved in the palm oil and construction industry, to conduct a comprehensive examination of the material's actual potential for reuse. Hence inter-disciplinary studies that encompass a broader spectrum is rudimentary to facilitate increased awareness and understanding of POC as a revived material for civil as well as other engineering applications. Fig. 7 shows the interaction between these issues and challenges.

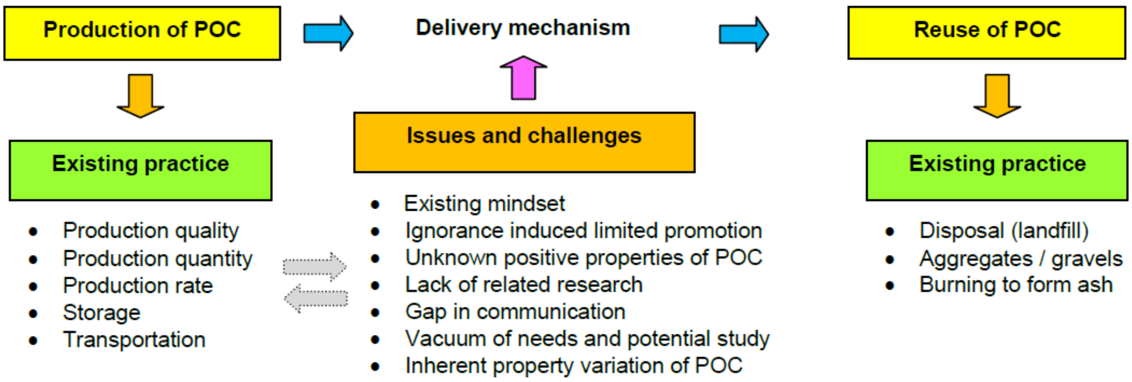

Fig.7. Issues and challenges in POC reutilization

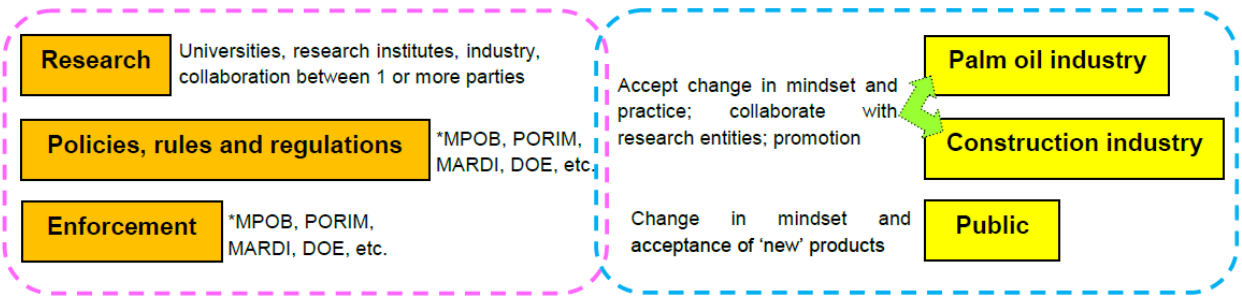

Fig.8. The "do's" and the "doers" to make it happen

*MPOB: Malaysian Palm Oil Board
*PORIM: Palm Oil Research Institute of Malaysia
*MARDI: Malaysian Agricultural Research and Development Institute
*DOE: Department of Environment

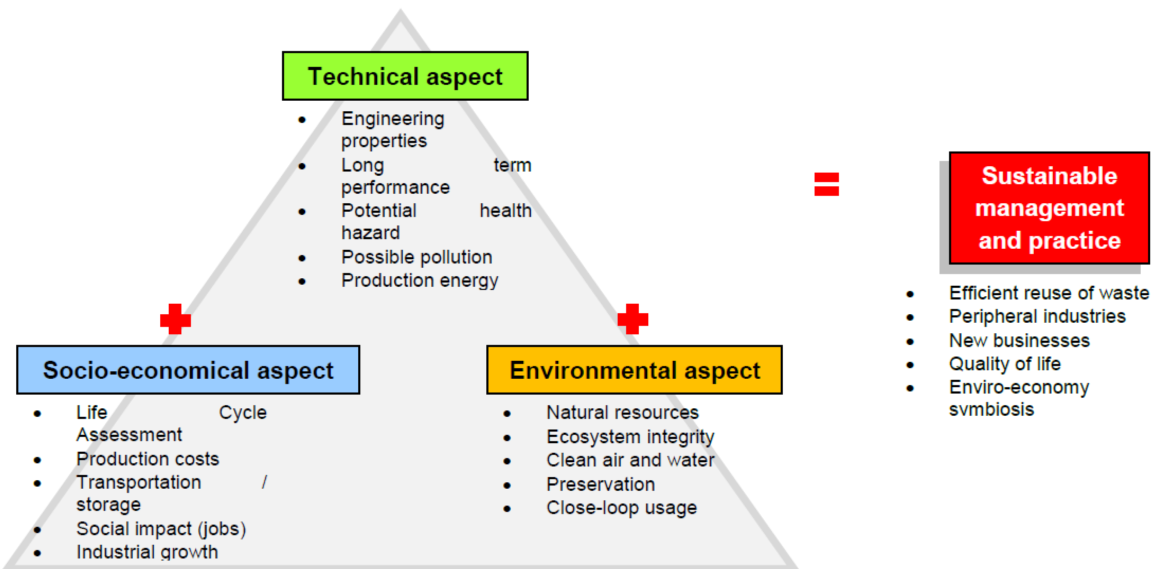

Fig.9. Conceptual framework for sustainable management and practice

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B. Making It Happen…

As illustrated in Fig. 8, to optimize the myriad reuse potential of POC requires several key players to join hands in collaboration. This involves not only the industry, but also the government agencies overseeing the relevant fields. New policies need to be established to ensure delivery of the products, but prior to that an awareness campaign is necessary to put POC in the limelight as a highly potential reusable material apart from the existing narrow-scoped practice. Guidelines, regulations and enforcement would be necessary to jumpstart the reuse of POC on a large scale, i.e. national level. It is only with knowledge can true enlightenment be attained, and full appreciation of the second lives of POC be realized. To achieve this, comprehensive research effort is compulsory, as the current database on POC is inadequate. Inter-disciplinary cooperation will help direct the development or preparation of the product to specific applications. This in turn will contribute to the development of new guidelines and safety measures, and to put in place specific QA and QC procedures for a feasible and effective monitoring system, from the production point to the consumer's end.

C. Framework for Sustainable Management and Practice: Key Elements

A holistic approach to establish the sustainability framework for POC reuse should be carried out by all the relevant parties. Firstly, the issues and challenges discussed earlier must be carefully addressed. The framework would cover all aspects of POC reuse, primarily including the technical, socio-economical and environmental areas. It requires the participation of all parties beginning from the production stage, delivery mechanism and ending with the consumers, who are mainly the builders and manufacturers. A conceptual outline is presented in Fig. 9. It can be seen that much of the work remains in research to furnish the database and a good grasp of POC's properties and behaviour. This could be taken as a cue to initiate more active studies in the targeted areas, to enable actualisation of the sustainable framework.

V. Conclusions

(a) 10 % addition of POC produced baked clay bricks with almost twice the strength of the ones added with the same amount of cement, highlighting the possibilities of replacing or substituting cement with raw POC in brick-making.

(b) A dosage of 15 % POC outmatched 5 % cement in improving a soft soil, promising to be effective and viable for soil stabilization. POC also provides long term stiffness enhancement to the soil compared to C-POC or cement alone.

(c) The POC greywater filter worked equally well as conventional sand filters in lowering the COD, BOD, SS and turbidity. Nonetheless trials with various sizes of POC particles in the multi-tiered filter are necessary to optimize the filtering mechanism. While it is acknowledged that further tests and long term monitoring are necessary before these applications can be implemented in the field, the preliminary sustainability framework clearly indicated the economic and added 'green' values of these second lives of POC.

Acknowledgment

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studied geotechnical engineering at Sheffield University, UK (2002-06) and is at present attached to the Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia. Having undergone a 2-year postdoctoral study at the Port and Airport Research Institute (PARI), Japan from 2009-2011, dabbling with the reuse of poor engineering soils in various applications, Dr. Chan is more convinced than ever that engineering works must be designed and executed within a sustainable framework to avoid being 'destructive'. Therefore, she has directed her effort towards conducting research studies in 'sustainable geotechnics', promoting the revival of wastes as well as discarded soils in a cross-disciplinary manner.

Dr. Alina Shamsuddin

graduated with a Ph.D. in technology management from Strathclyde University, UK (2007) and is currently a senior lecturer at the Faculty of Technology Management and Business, Universiti Tun Hussein Onn Malaysia. Equipped with a unique training and background in technology-cum-management, Dr. Alina explores the merging of the two, developing measurement tools, assessment models and various bridges to relate the diverse world of both. She is also a keen researcher in the design and development of strategic business models, particularly for small- and medium-size business with a technology base. Also an auditor for the prestigious Malaysian Qualifications Agency (MQA), Dr. Alina is well-versed with the academic systems and requirements, geared towards greater adaptability and compatibility to meet global demands.