GREEN MAINTENANCE FOR HERITAGE BUILDING: A PERSPECTIVE ON LATERITE STONES REPLACEMENT

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Abstract: The benchmark emphasised in research for maintenance of heritage building had been vitally set to support a sustainability concept. The discussion revolves throughout the economic, societal and environmental parameters. Primarily, low carbon repair had been given the main privilege in achieving sustainable repair and this was supported by 'Green Maintenance' concept and methodology. Previously, laterite stone replacement technique was recognised as a sustainable repair technique in term of their embodied carbon expenditure over a number of repair scenarios, represented by the total Environmental Maintenance Impact (EMI). The total of EMI is calculated through formulaic expression within 'cradle-to-gate' boundary of Life Cycle Assessment (LCA). Hence, this paper presents a detailed process of laterite stone replacement of heritage building located in Melaka Historical City, Malaysia. In the lens of 'Green Maintenance' concept and methodology, this paper also highlights the series of laterite stone extraction associated with the characteristic of laterite stones for heritage building purpose, quarrying method that reflects the energy content (carbon impact) and also the transportation impact. It is found that limited resourcing location is a main contributor of CO2 emissions in stone replacement technique. Significant effort should be done in re-opening old quarry or using salvaged material to reduce CO2 emissions in laterite stone replacement. Implicationally, 'Green Maintenance' had been proven as a practical tool in assisting the conservation players in making precise and nuanced decision-making in selecting the most sustainable repair in heritage building maintenance.

Keywords: Green Maintenance; Embodied Carbon Expenditure; Sustainable Repair; Laterite Stone; Heritage Building; Melaka

Introduction

Presently, the knowledge of maintenance had been wisely established due to conservation movement start in early 17th century (Kennedy, 2015). The ethic and principles as pillar of conservation philosophy of maintenance had been popularised by Forster (2010a; 2010b) read as least intervention, like for like material, honesty, integrity etc, mainly to ensure the high quality of repair. However, the existing implementation of maintenance is almost centred to the cost and budgetary allocation (Kayan and Forster, 2009). Whereas, the cost of repair is often perceived to be greater due to the usage of traditional materials and technique, specialist conservator operating in a market that associated with the high quality of craftsmanship (Forster and Kayan, 2009). Emphasised that the benefits accrued from investment of good maintenance are worthy in lowering the expenditure in long run and as an
asset, the value of heritage building will increase according to the quality of maintenance (Lateef, 2009).

In terms of environmental, heritage building is often claimed as a burden in terms of environmental performance (i.e. energy efficiency) that some urge the need of demolition or reconstruction (Ciniieri and Zamperini, 2013). In contrast, it is noted by Bell and Lowe (2000) that demolition of heritage building does not guarantee the sustainability of environment even 40% of the materials are recycled (Mckayte et al., 2008). Clearly, the ‘green issues’ of heritage building should be taken in a serious manner as environmental impact of heritage buildings is irreversible and the value embedded in their fabric is also irreplaceable (Earl, 2003, Pp. 3). Presently, maintenance had been largely accepted as necessary conservation activity as it provide an eloquent advantages from the aspect of cost, philosophical defensible and also capable of reducing environmental impact in the sustainability facets. Emergently, ‘Green Maintenance’ envisioned by Forster et al., (2011) had plays a vital role to promote low environmental impact of maintenance and repair through embodied carbon expenditure. Embodied carbon is principally known as CO₂ emissions released through the process of extraction, manufacturing, transportation of materials that consume a fair amount of energy in terms of electricity and fuels in maintenance and repair (Giesekam et al., 2016). It is the fact that 10% of CO₂ emissions are contributed from material sectors with the proportion of 70% and 15% associated with manufacturing and transportation respectively (English Heritage, 2007). In which, maintenance and repair of heritage are heavily depends on material sector. Ideally, ‘Green Maintenance’ concept and methodology provide the assessment of total embodied carbon expenditure represented by Environmental Maintenance Impact (EMI) and longevity of repair (frequency of repair) of maintenance intervention within ‘cradle-to-site’ of LCA boundary. Thus, the integration of EMI would encourages decision maker (authorities and conservationist) to align the environmental parameter inclusively with philosophical and budgetary concern to make a comprehensive, practical and informed decision making process prior to the selection of the most sustainable repair. The quantification approach of CO₂ emissions in maintenance and repair will be discussed in later section. On top, as the carbon abatement and green procurement is progressively become a critical concern; therefore this concept and methodology on quantification of CO₂ emissions contributed by maintenance and repair will be positively welcomed.

‘Green Maintenance’ Methodology

Theoretically, the correlations between CO₂ emissions are associated with number of repair, repair type and material usage as well as longevity of repair (frequency of repair) illustrated in represented in Equation 1 and Figure 1 (Kayan, 2015). Figure 1 shows the implication on undertaking maintenance and repair characterised by its longevity (l) and embodied carbon expenditure (Ce) in the service condition of heritage buildings over time. The downward sloping signifies the decline condition of the building where each intervention is important to keep the buildings at the optimal service condition, however also contributed to significant amount of CO₂ emissions through material requirements (extraction, manufacturing and transportation of material). Hypothetically, the more frequent of maintenance intervention, the greater embodied carbon expended (Forster et al., 2011). Commonly, preference is given to repair technique with higher longevity that subsequently incurred lesser number of repeated interventions and lesser-embodied carbon expenditure. Emphasised that there is another variables that should be considered: resourcing location, degree of exposure, building detailing, mode of transportation, technological development, quality of work and specifications (Kayan, 2015). Noted here, there are various mechanisms suggested in this concept and methodology to attain the reduction of CO₂ emissions in maintenance and repair such as usage of locally
sourced repair materials, engagement of companies to undertake repair work and selection low embodied carbon.

![Graph showing relationship between longevity of repair and embodied carbon expenditure.](image)

**Figure 1: Relationship Between Longevity Of Repair And Embodied Carbon Expenditure**

*Source: Forster et al., (2011), Kayan (2013)*

The total embodied carbon expended in the maintenance over a life span of buildings is calculated through a specific calculation procedure in following equation:

\[
\sum EMI_{\text{cradle} - \text{to} - \text{site}} = \text{Area repaired} \times [\text{Material used (t)} \times \text{Embodied Carbon Coefficient (ECC)} + \text{Material used (t)} \times \text{CO2 emission factor} \times \text{Resourcing location (km)}] \times \frac{\text{(Frequency of repair (n))}}{(100 \text{ year})}
\]

**Equation (1)**

Note:
ECC should be based on industrial generated of ICE Bath database by Hammond and Jones (2011)
CO2 Emission factor derived from Department of Environment and Rural Affairs (DEFRA) and Department of Energy and Climate Change (DECC, 2009)

To date, the applicability of ‘Green Maintenance’ methodology had been extensively tested in Forster et al., (2011,2013), Kayan (2013), Mahmud et al., (2016), Kayan et al., (2017a, 2017b; 2017c). In the context of laterite stones repair, several assessments using simplified formula underlined in Equation 1 had been conducted within the area of Historical City of Melaka specifically for St Paul’s Church and Bastion Middelburg (Kayan et al., 2017a; 2017b; 2017c; 2017d). Commonly, four repair techniques; stone replacement, plastic repair, pinning and consolidation and repainting of stones could be viewed in terms of relative levels of intrusion to the original fabric (Torney et al., 2014). Several repair scenarios within arbitrary maintenance period i.e. 100 year could be considered as it may bring a number of benefits relating to the technical, philosophical aspect of masonry conservation (see Figure 2). However, this paper concern about the stone replacement repair technique as it is recommended as most sustainable repair in previous research. Fundamentally, stone replacement is a repair involves in serious decayed stonework. It is necessary to remove greater quantities of original fabric and replace it with the matching one (Forster et al., 2011). Philosophically, the aim should be to retain the maximum amount of original stone, in case of inaccessible structure such as spires where the necessary scaffolding is expensive and not cost-effective in long term. Therefore, English Heritage, (2006) stressed on a careful sensitive repair of new stone replacement. In term of environmental, most of findings expounded that new laterite stone replacement emitted a high number of CO2 emissions due to quarrying, manufacturing process,
and transportation of material (see Kayan et al., 2017a; 2017b; 2017c; 2017d). But, stone replacement is practically done once, able to deal with high area of deterioration rather than plastic repair (mortar repair) and repointing (related to jointing mortar of wall) that informed to have lower longevity i.e. 25-30 year in 100 year of maintenance period. Comparatively, plastic repair is proven to have a low number of embodied carbon and also fundamentally good in term of conservation philosophy, however, it is important to consider about its major drawback on ability to deal with the large area of deterioration and suffering a lower longevity of repair, subsequently contributed large amount of CO2 emissions in 100 year (see Kayan et al., 2017a; 2017b; 2017c). Thus, it is sufficient to conclude that stone replacement is more ‘greener’ and sustainable in terms of embodied carbon expenditure rather than repointing and plastic repair due to its higher longevity (1 in 100 year) (Kayan, 2015).

![Repair Scenarios](image)

**Figure 2: Repair Scenarios**

*Source: Forster et al., (2011)*

On top, however, Hyslop (2004) expounded that the selection of stone in conducting of stone replacement is challenge demand of the suitably, matched, compatible with underlying substrate. Emphasised that the inappropriate stone may not only impair the appearance, but also cause physical damage to the remaining original materials and resulting a greater cost i.e. wasted time and money (Hyslop, 2006). As ‘Green Maintenance’ had underlined stone replacement as most sustainable repair technique, this paper aimed to extend the practicality of conducting this technique by review the series of process in conducting laterite stone replacement, evaluated within ‘cradle-to-site’ boundary of LCA for laterite stone replacement of selected heritage buildings located in Historical City of Melaka.

**Laterite Stone Profile**

Laterite has become the subject of controversies due to its nature of formation and genesis of lateritic materials (Paramanthan and Thammarajan, 1983). In depth, the formation of laterite was perceived as product of weathering (metasomatic rock) in 1800 and in the middle of twentieth century, attention had been focused on geochemistry of weathering (dry and wet condition) and suitable geological condition i.e. plateau with varying alluvium character and topography and that influenced the chemical laws or known as laterisation in soil (Ahmad and Hoe, 2002). Many hypotheses have been advanced to essentially differentiate the weathering processes exhibit by rocks and laterisation in soil, however, it is found that differentiation is only revolves the unique process in achieving a considerable mineral and chemical content, enhanced by climate condition (repetitive wet and dry season) to speed up the leaching process (Pendleton, 1941).

The aforementioned process is also associated with the physical appearance of laterite stone. Physically, laterite manifested as spongy coarse, ferruginous rough material varying in
colour from white, yellowish, rusty red to liver colour, brown material or almost black with lilac-tinted lithomarge earth depending on the mineral and chemical content such as ferrous iron, aluminium, kaolinite clay that is also known as sesquioxide content formed in the hot and wet tropical area (Adekunle et al., 2014). For example, whitey colour of laterite occurred due the domination of kaolinite clay and red for ferrous iron. As far the construction is concerned, laterite has unique properties as a soft material until it can cut using spade to be made into regular block and harden after exposure (Noronha et al., 1998). It is mainly due the reaction between sesquioxides content and air, which enhances a good bond with other particles, known as oxidation process (Varghese, 2015). As building material, the accumulation of sesquioxides will influenced the method of extraction process, appearance, strength and porosity as important criteria selecting compatible material in repairing heritage building (Historic Scotland, 2013). On top, it is broadly known that laterite stone offers good strength and durability as building material showed by numerous heritage building that now is still stand nobly through conflicts and with the test of time under tropical hot climate.

![Laterite Stone](image)

Figure 3: Laterite Stone
Source: Author (2017)

In Historical City of Melaka, Malaysia, there are three (3) significant heritage buildings known as remaining part of Melaka Fort, that being conserved with different nature of maintenance and repair. Historically, St Paul’s Church and Porta de Santiago (a gate of A Famosa) was mainly built by laterite stones believed to be sourced from Ilha de Pedros (Pulau Upeh, Melaka, Malaysia) and Cape Ricardo (Port Dickson, Negeri Sembilan near to Lukut Fort) where the fact can be seen on laterite cutting over the island (Tan, 2015). Additionally, the sample taken from Porta de Santiago (a gate of A Famosa) was found to have a similar mineral content, chemical properties reflecting the origin of laterite stone (JWN, 2006). Meanwhile, in 2008, after the excavation project, Bastion Middelburg (see Figure 4) is then reconstructed by using laterite stones based on ‘like-for-like’ repair strategies (JWN, 2008). The reconstruction of Bastion Middelburg was consistently facing difficulties in finding the locally available original stones in large scale. Then, large volume of laterite stones were mainly sourced from Pranchiburi, Thailand that was about 1,797km from Melaka Historical City (JWN, 2008). Comparatively, for St Paul’s Church, several interventions had been done in between 2003 to 2012. Surprisingly, it is found that several portion of the wall had been replaced by brick (see Figure 5). It is noted that the implementation of maintenance for St Paul’s Church had been done partially with proper guidelines before the establishment of Jabatan Warisan Negara in 2005. Subsequently, this issue need a further discussion on compatible but imported material and incompatible but locally sourced from short distance. Prior to that, both cases of stone replacement were questionable particularly on the availability of laterite stones (quarry site, alternative materials such as salvaged material) to deal with different scale of project, cost of implementing, philosophical judgement that incorporated with the environmental impact (CO₂ emissions) as one of critical concern of ‘Green Maintenance’ concept and methodology.
Sources of Stone Used for Laterite Stone Replacement

First, significant efforts should be made to identify the original source of laterite stone to be utilised in maintenance and repair. In all, stone selection for stone replacement demands the combined skills and knowledge of experienced in working with stone such as geologist or petrographer (English Heritage, 2006). In Peninsular Malaysia, the main soil associated with laterite cover about 5.9% of the land (Law and Selvadurai, 1968) where the largest areas of laterite composition are found to be along Kedah, the Port Dickson-Likam coast and Muar-Temceloh strip (see Map 1) had become an open door for making it as local construction product. It is believed that utilisation of laterite stone in Melaka is due to their nature where it is locally abundant in southern part of Peninsula Malaysia, where the quarry location occupies near to the coastal and river area which no long in operation i.e. Sungai Raja, Tanjung Dahan at Negeri Sembilan and Pulau Upeh, Melaka. Hyslop (2006) elaborated that the nature of stone from existing quarry can be change over time, where the seam may not longer compatible to suit the demand of repair. The issue is, due to the scarcity and the demand of conservation that need bigger volume of laterite stone would sometimes cause out-sourcing of new stone is one of unavoidable. Subsequently, this process possessed high environmental impact specifically for transportation. ‘Green Maintenance’ highlighted that locally sourced material as one of the important mechanism in reducing CO2 emissions. Clearly, the preferences should be given to the stone that are primarily located near to site, reclaimed from demolished buildings or sourced from a local stone quarry that likely reduce the embodied carbon figure (English Heritage, 2006).
It is noted on the availability of laterite resources throughout Peninsula Malaysia could alternatively used in repairing the existing structure. Logically, there are another problems that need to be considered within the availability of laterite resources particularly on how to incorporate with the existing built up area, transportation linkages (overlaid using GIS in Map 1), ownership of the land and also safety requirements. For example, the transportation linkage to Sungai Raja, Negeri Sembilan that reported by technical liaisons from Lukut Fort Museum as one of the biggest laterite resourcing location to built Lukut Fort is not accessible by commercial vehicles. Presently, laterite stone is also observed being used by the villagers in Melaka as boundary wall and locally abundant near to residential area, however Guidelines for the Siting and Zoning of Industry and Residential areas in the section of quarrying activity published by Malaysia Department of Environment (DOE) on 2012 demand a buffer zone as part of safety requirement that need to be considered eloquently. Currently, the marketplace of mineral production, in specific laterite stone is also absent to support the need of laterite stone replacement. Schellman (1979) suggests bauxite as one of variety of laterite based on mineral classification. However, the production of bauxite in Malaysia is purposely for aluminium production (JMG, 2013). Clay is also classified as lateritic material in Malaysian Mineral Yearbook (JMG, 2010). Briefly, it found that the production of clay is largely concentrated in Perak and Terengganu which contradictory to the distribution of laterite resources. These indicate that the production of laterite is not existed in the percentage of the clay production.
Clearly, the limitation discussed is sufficiently explained the justification of the usage of imported stone from Pranchiburi, Thailand to deal with large volume of laterite stones in reconstruction of Bastion Middelburg. Due to the limited choice for stone, the repair-construction need to undergo some complex process such as quarrying, processing and transporting, which contributes to high embodied carbon (Hu and Wang, 2006). However, when obtain a reduction in CO₂ emissions, it is suggested that significant effort on re-opening the old quarry or known as snatch quarrying, opened for a temporary basis should be made to obtain a limited supply of stone rather than used a brick with unknown durability and not acceptable in term of conservation (Hyslop, 2006). For example, the large availability of laterite stones at old quarry of Pulau Upeh, Melaka can be potentially optimised in conducting stone replacement in small-scale maintenance project at St. Paul’s Church [see Figure 6]. ‘Green Maintenance’ provides as basis of 1m³ of repair in order to quantify CO₂ emissions, in which, typical amount of stone needed is around five (5) blocks of stone. In simple, out-sourcing of material in conducting stone replacement is not worth in terms of cost and environmental impact particularly on transportation part. Alternatively, if there is no other available quarry, the usage of salvaged materials is emphasised in conducting stone replacement repair technique. It perhaps can be obtained from various source such as abandoned old buildings, demolished building structures, building suppliers, salvaged contractors and use-material dealer (Ramlil and Byrd, 2012). Conversely, however, selection salvaged material of laterite stone for stone replacement is not as easily incorporated in practices, which requires locating the source early and comprehensive planning in early phase of conservation work.

![Figure 6 Laterite Stones at old quarry of Pulau Upeh, Melaka](Source: Author (2017))

**Extraction and Quarry of Laterite Stone**

The recognition of either old quarry or extent quarry is a must in selection of stone (Ashurt and Ashurt, 1988). To obtain the laterite stones for conducting laterite stone replacement, there is considerable step need to be undertaken. The general extraction process of laterites can be resource intensive both in labour and cost. However, could be easily being augmented through the use of energy by using mechanised tool and vehicles. The general step may include overburden removal, primary cutting, storage of material on site and also transportation process (see Figure 7). The detailed chart in Figure 7 developed through a systematic review of conservation report of Reconstruction of Bastion Middelburg in 2008 and Industrial Research of Laterite Stone and the relationship between Melaka Fort in 2002, supplemented with other relevant literatures and site visit. Relevantly, the pattern of extraction of laterite is found to be similar throughout the world.

Based on previous discussion, it is important to note about the formation of laterite incurred in either soil (plinthe) within pallitic zone or the large boulder of laterite. Reported by JWN (2008) that laterite from Pranchiburi, Thailand is formed in soil meanwhile in Pulau
Upeh, the large amount of laterite bed is found abundant over the island, where it is locally known as Pulau Batu before. To obtain laterite, first, overburden removal need to be done at least a foot or more below water-table as it getting wet and softer with depth and offers excellent quality for all purposes (Noronha et al., 1998). For the large bed of laterite (laterite boulder) is nearly undisturbed, only the loose materials are removed from surface (Pendleton, 1941). After the surface has been smoothed off either manually removed by hand, dozer or hydraulic shovels, usually the levelling process will taken immediately to determine the horizontal bed of laterite and marking line using manual measurement equipment [see Figure 8] (Kasthurba et al., 2014). In Pulau Upeh, it is found the similar pattern of size ranging about less than 600 x 300 x 300 mm of stone which indicate that measurement of stone had been precisely in site to built Melaka Fort. In which, no secondary cutting is occurred.

![Figure 8 Marking lines process on the top of laterite soil in Goa, India](image)

Laterite then will be cut into square blocks through the lines marked and desired depth. To date, the use of machinery for quarry known as cutter with tungsten carbide bits or mechanised mobile rotatory saw [see Figure 9] in the last decade resulted in large-scale of production of laterite and reduce the wastage to meet the growing demand (Kasthurba et al., 2007). However, in practice, the wastage of laterite will be stored as a rubble stone (Noronha et al., 1998). In the past, any iron instrument is used to cut and dig up into square masses to thickness of the blocks with pickaxe and immediately cut into a shaped by using trowel or large knife (Pendleton, 1940) [see Figure 10]. The evidence is also found in Pulau Upeh, Melaka where it had been cut smoothly about 2 inches, parallel to the usage of pickaxe [Figure 11]. Whereas, for laterite in soil, the characteristic of laterite is ranging depend on their depth. Pendleton (1952) suggest on digging to approximately about 50cm in Ceylon and few centimetres to 180cm from the top of soil in Thailand. Meanwhile, Kasthurba et al., (2014) reported on 520cm or to the depth of 25metres in Goa and Malabar region in West India. The depths of cut will determine the capacity of water absorption that subsequently will influence the strength and density of laterite stone, greater enhanced by the process of oxidation after exposure (Kasturba et al., 2007). It is proven that the usage of laterite stones for heritage building in Melaka that is sourced from the seacoast area part of valuable knowledge of stonemason during the Portuguese era. The maximum thickness observed to be found near to seacoast area (water access) in Malaysia (i.e. Tanjung Dahan and Pulau Upeh). Throughout the process, laterite stones need to expose to turn the material into a hard block, either in situ or transported to the storage location (Adekunle et al., 2014).
To cater the demand of maintenance and repair that tightens with certain specification, the stone may need to endure a secondary processing, and transported to the construction site. Logically, the mimic of original stone need to be carefully followed, where secondary processing is only related to cutting process to fit the scam of existing building. For the case of imported stone, it is crucial to detail up the requirements of vehicles as the laterite stone need to be fully covered up from the rain until the complete cycle of oxidation [6-12 months] (Duggal, 2008). Ideally, throughout the process of extraction and quarrying of laterite associated with the energy usage (carbon content) is not a main impetus of CO2 emissions. The embodied energy reported by Praseeda et al., (2014) is solely related to diesel operated machine due to primary cutting process either in soil or on bed of laterite (0.0069MJ/kg contributed in 1 block of laterite with 400 x 200 x 250 mm). Comparatively, if the process is handled manually, there will be zero impact of CO2 emissions on extraction and quarrying. Therefore, the CO2 emissions for stone replacement are found dominated by transportation process.
However, using a locally sourced material may reduce CO2 emissions. In the case of locally sourced from old quarry of Pulau Upeh, based on current seawater, there is two important considerations need to be taken into account, which are suitable timeframe to deal with water-tide where in the low water tide, large amount of laterite stones will be fully exposed that allowed more stone to be extracted and also appropriate transportation mode such as boat and commercial transport to the jetty and site. In practice, the appointed conservator and experts in stonemason also plays a vital role in succeeding the implementation of sensitive repair of laterite stone replacement.

![Process Map of Laterite Stone Replacement](image)

**Figure 7 Process Map of Laterite Stone Replacement**

**Source:** Author (2017)

**Conclusions**

The ‘Green Maintenance’ concept and methodology prioritised the important of environmental impact in evaluating maintenance and repair. Prior to that, stone replacement is suggested as most sustainable repair based on embodied carbon expenditure and high longevity in long run through the calculation of EMI. In other branch, the strong realisation conservation philosophy knowledge i.e. ‘like-for-like’ repair strategies among the authorities after the
establishment of Jabatan Warisan Negara, had urge the need of out-sourcing of material from foreign country, due to the limited resourcing location of laterite stones. Subsequently, this process had contributed to the large amount of CO₂ emissions mainly due transportation process. However, suggested here that the old quarry of Pulau Upeh need to be re-opened for a small-scale of maintenance work. In the perspective of ‘Green Maintenance’ that encourages a low embodied carbon, this paper had discovered the nature of laterite stone extraction mainly in Thailand, Pranburi and Pulau Upeh by developing a process map of stone replacement. The indication showed that CO₂ emissions of stone replacement are only contributed through the usage of mechanised tool in primary cutting and transportations process. Proven that, locally sourced material and manually handled in primary cutting will contributed to very low CO₂ emissions. Development of process map of extraction of laterite stone within ‘cradle-to-site’ in this paper need to be further tested using the equation as previously research postulating on that stone replacement emitted high number of CO₂ emission and quite contradictory with current literature. However, it is undeniable, the consideration of ‘Green Maintenance’ concept and methodology that envisioned to reduce the environmental impact had allowed a greater analysis of another dimensions (conservation philosophy and cost) to became more realistic in the decision-making process.

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