

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

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**Abstract:** *The benchmark emphasised in research for the maintenance of heritage building had been vitally set to support a sustainability concept. The discussion revolves throughout the economic, societal and environmental parameters. Primarily, the 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 terms 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, the goal of this paper is to explore and expand the practicality of laterite stone replacement technique utilised for heritage buildings located in Melaka Historical City, Malaysia, in the lens of 'Green Maintenance' concept and methodology. Subsequent discussion highlights the series of process incurred in conducting laterite stone replacement within the boundary of 'cradle-site', by considering the character of laterite stone for building purposes, quarrying method that reflects the energy content (carbon impact) and also the transportation impact. It is found that limited resourcing location is the main factor of high-emitted CO<sub>2</sub> emissions in stone replacement technique. Therefore, significant effort should be made in re-opening an old quarry or using a salvaged material to reduce CO<sub>2</sub> 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 maintaining heritage buildings.*

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

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### Introduction

Presently, the knowledge of maintenance had been established due to a conservation movement started in the early 17<sup>th</sup> century (Kennedy, 2015). The ethic and principle acts as a pillar of conservation philosophy that had been popularised by Forster (2010a; 2010b) known

as least intervention, like for like material, honesty, integrity, etc., mainly to ensure the highest quality of repair, better compatibility, highly defensible, greater longevity than insensitive, often inappropriate repairs (Kayan, 2016). However, it is not surprising that a budgetary allocation was one that overarching priority in a current practice and this became a great concern of the decision makers (Forster and Kayan, 2009). The cost of repair in undertaking maintenance perceived to be greater due to philosophical tenets that demand the uses of traditional material, sophisticated repair technique and the need to use specialist subcontractor operating in a market (Forster and Kayan, 2009), whilst current functionality of buildings, timescales in conducting a project and to avoid an unnecessary cost prioritised by a client made this a clear dilemma (Gold and Rubik, 2009). However, Hill (1995) strongly believes that that ability to ensure high quality of repair that complies with the conservation philosophies does not always expensive and the benefit accrued from the investment of good maintenance and repair are worthy in lowering the expenditure in a long run (Lateef, 2009). Progressively, the discourse of maintenance and repair should be expanded by not only focuses on protection of fabric of heritage building and cost of implementation but also need to address the environmental impact of any intervention undertake. In the 21<sup>st</sup> century, the integration of sustainability has emerged a dominant theme in the recent debate of maintenance and repair through good maintenance strategies and effective repair work (Kayan, 2017). Whilst, the environmental domain has become a main privileged in the current system thinking and this opens a critical concern on environmental decision-making process (WWF, 2016).

Emergently, ‘Green Maintenance’ concept envisioned by Forster et al., (2011) draw a generally accepted model of sustainable development to gain a consistent measurement; society, economic, and environmental (Kayan et al, 2016) and subset of these parameters described that any evaluation of maintenance intervention should be based on conservation philosophy, cost and low environmental impact (see Figure 1). Therefore, any intervention that interlaid with these three parameters will be considered as most sustainable repair. However, the evaluation of environmental impact of maintenance is being ignored in academia alike (Kayan, 2013). It is observed that the efforts of the current assessment and tools given for maintenance and repair are concentrated on dilapidation survey, laboratory test and isolated field studies (Kamaruzzaman et al., 2011) or often reduce to the building-retrofitting decision specifically to improve the mechanical systems [energy efficiency] (Margini and Franco, 2016). Meanwhile, the current precedent scheme on Green Building Rating (GBR) i.e. Green Building Index has suffered a lack of universality in order to calibrate into the actual performance of maintenance and repair of heritage buildings (Cabeza et al., 2013). It is important to note that any installations of modern equipment and tools to boast their energy efficiency were often incompatible, unfeasible and the payback of the energy consumption is always questionable (Young, 2011). It is clear that deficiency of old buildings to perform as a new building in term of their energy performance due to several restrictions; construction technique, typological and functional features (Loron et al., 2015). However, Forster (2016) stressed that the natural remedies are already served on their maintenance and repair, therefore need to be progressed as heritage building has almost innumerable tonnes of embodied carbon locked up in its fabric and there is much can be learnt from the existing restrictions. In this case, Forster et al., (2011; 2013) raised the vital role to promote a low environmental impact of maintenance and repair through embodied carbon expenditure. Embodied carbon is principally defined as CO<sub>2</sub> 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 CO<sub>2</sub> emissions are contributed by the usage of traditional material with the proportion of 70% and 15% associated with manufacturing and transportation respectively (English Heritage. 2007). Ideally, ‘Green Maintenance’ concept and methodology provide an assessment of cumulative embodied carbon expenditure represented by Environmental Maintenance Impact (EMI) and longevity of repair (frequency of repair) of maintenance intervention within ‘cradle-to-site’ of Life Cycle Assessment approach. Thus, the integration of EMI would encourage 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 CO<sub>2</sub> emissions in maintenance and repair will be discussed in later section. Conceptually, this paper intends to explore the applicability of results produced by ‘Green Maintenance’ concept and methodology to reflect the ground implementation. On top, as the carbon abatement and ‘green procurement’ is progressively becoming a critical concern; therefore this concept and methodology will be positively welcomed.

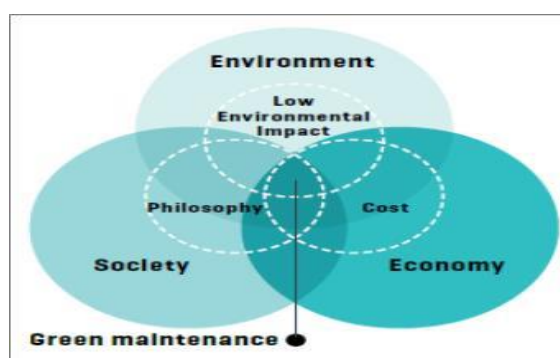
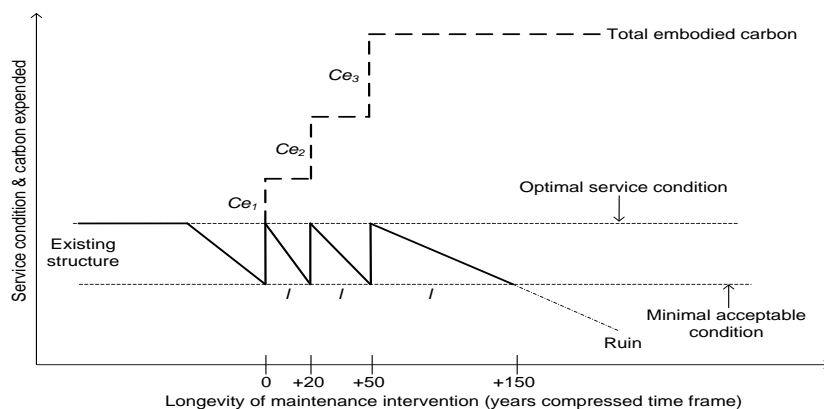


Figure 1: ‘Green Maintenance’ conceptual model  
Source: Forster et al., (2011), Kayan (2013)

### ‘Green Maintenance’ Methodology

Theoretically, the correlations between CO<sub>2</sub> emissions are associated with the number of repairs, repair type, and material usage as well as longevity of repair (frequency of repair) illustrated in represented in Equation 1 and Figure 2 (Kayan, 2015). Figure 2 shows the implication on undertaking maintenance and repair characterised by its longevity ( $I$ ) and embodied carbon expenditure ( $C_e$ ) 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 contributed to a significant amount of CO<sub>2</sub> emissions through material requirements and procurement (extraction, manufacturing, and transportation of material). Hypothetically, the more frequent of maintenance intervention, the greater embodied carbon expended (Forster et al., 2013). Commonly, preference is given to repair technique with higher longevity that subsequently incurred a lesser number of repeated interventions and lesser-embodied carbon expenditure. Emphasised that there are another variables that should be considered; resourcing location, a degree of exposure, building detailing, mode of transportation, technological development, quality of work and design specifications (Kayan, 2015). Noted here also, there are numerous mechanisms suggested in this concept and methodology to attain the reduction of CO<sub>2</sub> 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 (Kayan, 2013).



**Figure 2: Relationship between longevity of repair and embodied carbon expenditure**

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

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

$$\Sigma EMI \text{ cradle-to-site} = \text{Area repaired} \times [\text{Material used } (t) \times \text{Embodied Carbon Coefficient } (ECC) + [\text{Material used } (t) \times \text{CO}_2 \text{ emission factor} \times \text{Resourcing location } (km)] \times (\text{Frequency of repair } (n)) / (100 \text{ year})$$

**Equation (1)**

Note\*

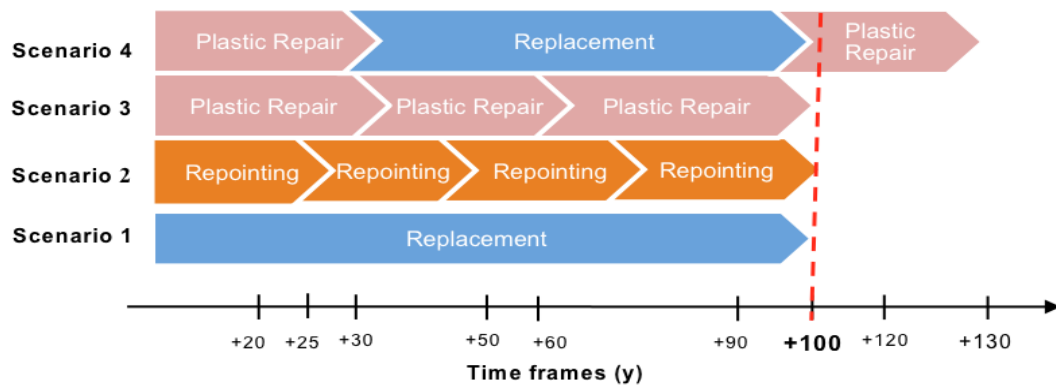
ECC should be based on industrial generated of ICE Bath database by Hammond and Jones (2011)

CO<sub>2</sub> Emission factor derived from Department of Environment and Rural Affairs (DEFRA) and Department of Energy and Climate Change (DECC, 2009)

### ***Review of Tested ‘Green Maintenance’ for Laterite Stones Repair in Melaka***

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;2018). In the context of laterite stones repair, assessments of repair works had been taken within the heritage buildings located in Melaka Historical City specifically for St Paul’s Church and Bastion Middelburg, and the results were formulated using simplified formula underlined in Equation 1 (Kayan et al., 2017a; 2017b; 2017c, 2018). Primarily, four repair techniques; stone replacement, plastic repair, pinning and consolidation and repointing 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 years could be considered as it may bring a number of benefits relating to the technical, philosophical aspect of masonry conservation (see Figure 3). However, this paper concern about the stone replacement repair technique as it is recommended for most sustainable repair in previous research. Fundamentally, stone replacement is a repair involves in the 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 an inaccessible structure such as spires where the necessary scaffolding is expensive and not cost-effective in long-term (English Heritage, 2006). Therefore, English Heritage (2006) stressed on a careful sensitive repair of new stone replacement. In term of environmental, most of the findings expounded that the utilising of new laterite stone for replacement will emit a high number of CO<sub>2</sub> emissions in the process of quarrying, manufacturing and, transportation of material (see Kayan et al., 2017a; 2017b; 2017c). However, emphasised that the stone replacement is practically done once, able to deal with a 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 years of the maintenance period. Comparatively, plastic repair is also 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 the major drawback on its ability to deal with the large area of deterioration and suffering a low longevity of repair, therefore contributed large number of CO<sub>2</sub> emissions in 100 year (see Kayan et al., 2017a; 2017b; 2017c; 2017d, 2018). 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) (Forster et al., 2013, Kayan, 2015).



**Figure 3: Repair Scenarios**

Source: Kayan et al., 2017a; 2017b; 2017c;2017d

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 the underlying substrate. Prominently, the inappropriate stone may not only impair the appearance but also cause physical damage to the remaining original materials and be 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 processes 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 in Melaka Historical City

Laterite stones (see Figure 4) have become the subject of controversies due to its nature of formation and genesis of lateritic materials (Paramanathan and Tharmarajan, 1983). Generally, the formation of laterite was perceived as product of weathering (metasomatic rock) in 1800 and in the middle of the twentieth century, the 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 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 the rocks and laterisation in a soil. However, the differentiation is only revolved the unique process in achieving a specific mineral and chemical content (Fe<sub>2</sub>O<sub>3</sub>, SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub>) that is enhanced by climate condition (repetitive wet and dry season) to speed up the leaching process (Pendleton, 1941).

The aforementioned processes are also associated with the physical appearance of laterite stones. Physically, laterite stones is 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, a whitey colour of laterite occurred due to the domination of kaolinite clay and red for ferrous iron. The content has made laterite stones as a unique building material; soft material until it can cut using a spade to be made into a regular block and harden after exposure (Noronha et al., 19998). It is mainly due to the reaction between sesquioxides content and air exposure, which enhances a good bond with other particles, known as oxidation process (Varghese, 2015). As a building material, the accumulation of sesquioxides will influence the method of the extraction, appearance, compressive strength and porosity as important criteria selecting compatible material for repairing heritage building (Historic Scotland, 2014). Broadly, laterite stones offer a good strength and durability as building material showed by numerous heritage building that now still stands over the worlds through conflicts and with the test of time under tropical hot climate.



**Figure 4: 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 5) is 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, the large volume of laterite stones was 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 (JWN, 2012). Surprisingly, it is found that several portions of the wall surface had been replaced by brick (see Figure 6). 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 (JWN, 2012, Jamin, 2017). Subsequently, this issue needs a further discussion on compatible materials but imported and incompatible but locally sourced from a 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 (CO<sub>2</sub> emissions) as one of critical concern of 'Green Maintenance' concept and methodology.



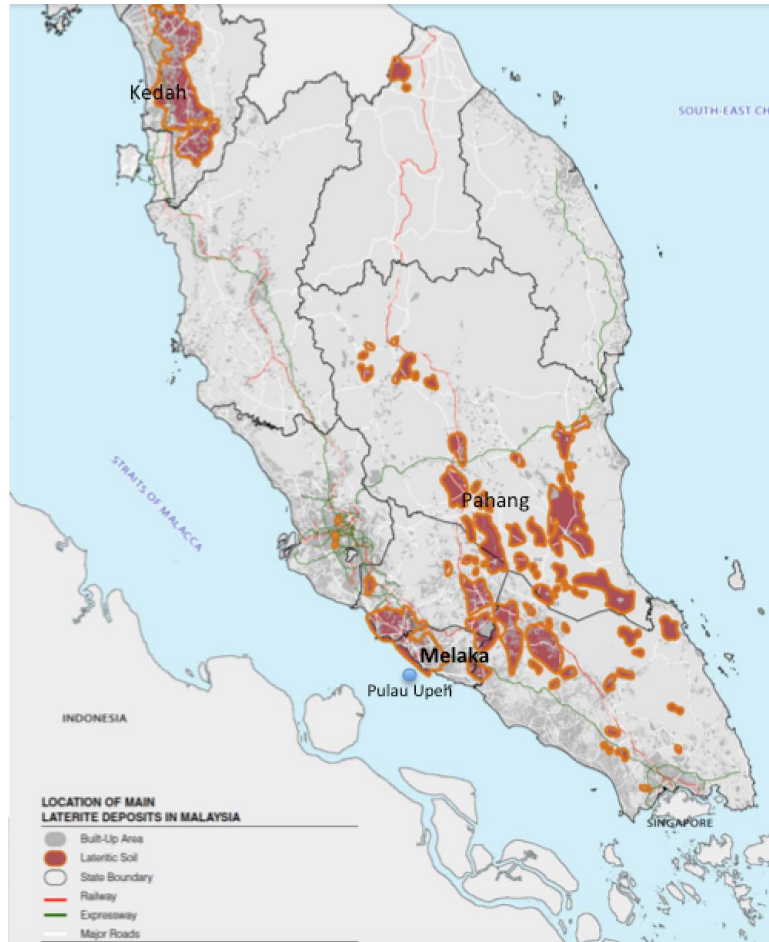
**Figure 5: Bastion Middelburg**  
Source: Author (2016)



**Figure 6: Laterite Stone**  
Source: Author (2017)

### ***Sources of Stone Used for Laterite Stone Replacement***

First, significant efforts should be made to identify the original source of laterite stones in order to be utilised in maintaining heritage buildings. Stone selection for replacement demands the combined skills and knowledge of experience in working with stone such as stone consultant, usually a geologist or petrographer (English Heritage, 2006). In Peninsular Malaysia, the main soil associates 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-Melaka coast and Muar-Temerloh strip (see Figure 7) 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 the southern part of Peninsular Malaysia, where the quarry location occupies near to the coastal and river area which no longer 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 no longer compatible to suit the demand of repair. However, due to the scarcity and the demand of conservation that need a bigger volume of laterite stones would sometimes cause out-sourcing of new stone is one of unavoidable. Subsequently, this process possessed high environmental impact specifically in transportation activity and process. Eloquently, the ‘Green Maintenance’ highlighted that locally sourced material as one of the important mechanism in reducing CO<sub>2</sub> emissions. Clearly, the preferences should be given to the stone that is primarily located near to the site, reclaimed from demolished buildings or sourced from a local stone quarry that likely reduce the embodied carbon figure (English Heritage, 2006).



**Figure 7: Location of Laterite Deposits in Peninsular Malaysia**

Source: Eyles (1970), enhanced through Malaysia National Physical Plan-2

It is noted on the availability of laterite resources throughout Peninsular Malaysia could alternatively be used in repairing the existing structure. Logically, there are other 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 Figure 7), 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 stones resourcing location to built Lukut Fort were inaccessible 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 for laterite stones replacement. Schellman (1979) suggests bauxite as one of a variety of lateritic material 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 is found that the production of clay is concentrated in the area of Perak and Terengganu which contradictory to the distribution of laterite resources. These indicate that the production of laterite is had not existed in the percentage of the clay production.



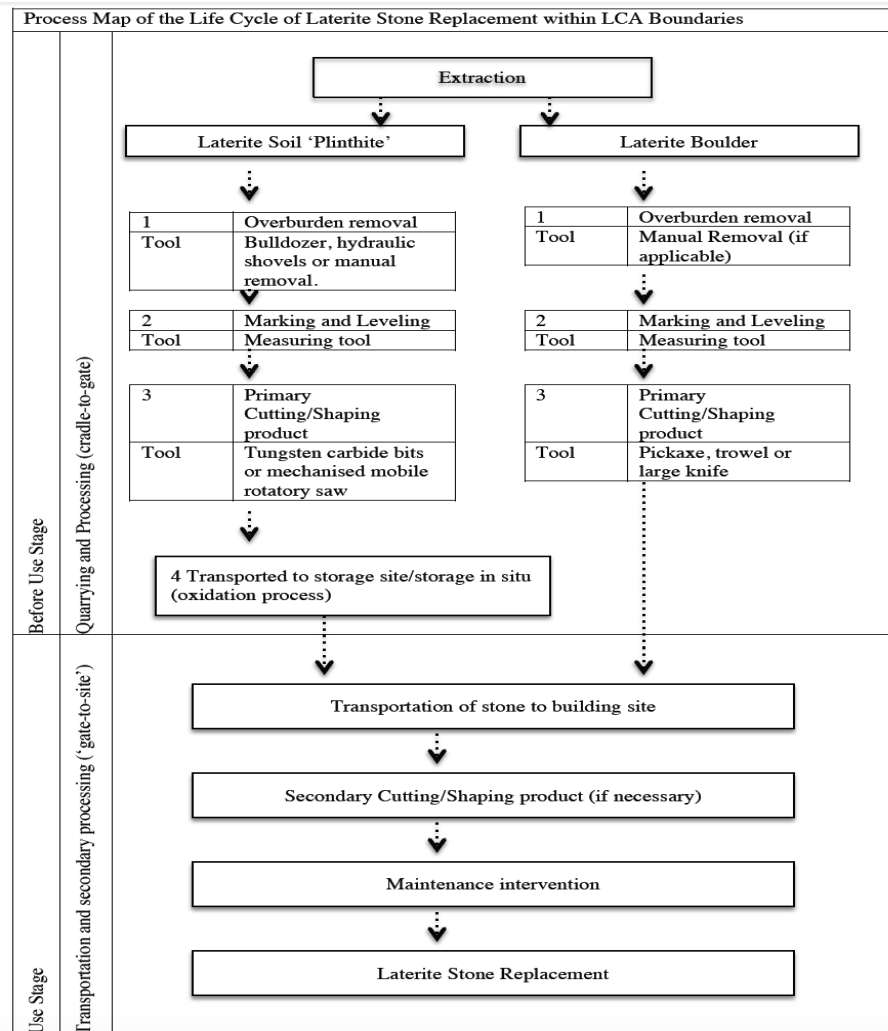
Clearly, the limitation discussed is sufficiently explained the major justification of the usage of imported stone from Pranchiburi, Thailand to deal with large volume of laterite stones in the reconstruction of Bastion Middelburg. Due to the limited choice of stone, the repair-undertaken need to undergo some complex process such as quarrying, processing and transporting, which contributes to high-embodied carbon (Hu and Wang, 2006). However, to attain a reduction in CO<sub>2</sub> 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 terms of conservation (Hyslop, 2006). For example, the large availability of laterite stones at the 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 8). 'Green Maintenance' methodology provides a basis of 1m<sup>2</sup> of repair in order to quantify CO<sub>2</sub> emissions, in which, a 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 sources such as abandoned old buildings, demolished building structures, building suppliers, salvaged contractors and use-material dealer (Ramli and Byrd, 2012). Conversely, however, selection salvaged material of laterite stone for stone replacement is not as easily incorporated in practices, whereby it requires locating the source early and comprehensive planning in the early phase of conservation work.



**Figure 8: Laterite Stones at old quarry of Pulau Upeh, Melaka**  
Source: Author (2017)

### ***Extraction and Quarry of Laterite Stone***

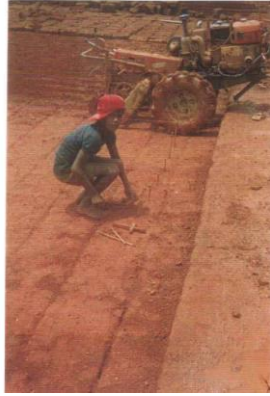
The recognition of either old quarry or extent quarry is a must in a selection of stone (Ashurt and Ashurt, 1988). To obtain the laterite stones for conducting laterite stone replacement, there is considerable steps need to be followed meticulously. The general extraction process of laterite stones can be resource intensive both in labour and cost. However, could be easily be 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 9). The detailed chart in Figure 9 is developed through a systematic review from conservation report of Reconstruction of Bastion Middelburg in 2008, Industrial Research of Laterite Stones and its relationship to Melaka Fort published in 2002 by Jabatan Warisan Negara and also supplemented with other relevant work of literature and site visit to the old quarry of Pulau Upeh. Relevantly, the pattern of extraction of laterite is found to be similar throughout the world.



**Figure 9: Process Map of Laterite Stone Replacement**

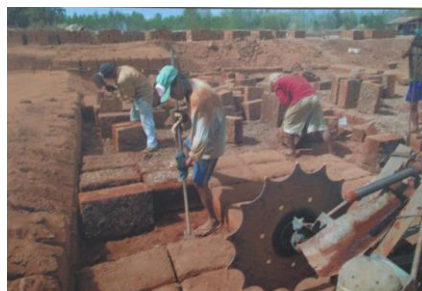
Source: Author (2017)

Based on the previous discussion, it is important to aware that the formation of laterite is incurred in either soil (plinth) within pallitic zone or the large boulder of laterite rock. Reported by JWN (2008) that laterite from Pranchiburi, Thailand is formed within the soil. In Pulau Upeh on the other hand, the large number of laterite beds were found abundant over the island, where it is locally known as Pulau Batu before (JWN, 2002). To obtain laterite, first, overburden removal needs to be done at least a foot or more below water-table as it getting wet and softer with depth and may offer 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 the surface (Pendleton, 1941). After the surface has been smoothed off either manually removed by hand, dozer or hydraulic shovels, usually the levelling process will be taken immediately to determine the horizontal bed of laterite and marking a line using manual measurement equipment [see Figure 10] (Kasthurba et al., 2014). In Pulau Upeh, it is found the similar dimension of size ranging about less than 600 x 300 x 300 mm of blocks. This indicates that the measurement of stone had been precisely done on the site (in situ) to built Melaka Fort. In which, no secondary cutting has occurred.



**Figure 10: Marking lines process on the top of laterite soil in Goa, India**  
Source: Noronha et al., (1998)

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 a cutter with tungsten carbide bits or mechanised mobile rotatory saw (see Figure 11) in the last decade resulted in large-scale of production of laterite and reduce the wastages to meet the growing demand (Kasthurba et al., 2007). However, in practice, the wastage of laterite will be stored as a rubble stones (Noronha et al., 1998). In the past, any iron instrument is used to cut and dig up into square masses to the thickness of the blocks with a pickaxe and immediately cut into a shape by using a trowel or large knife [see Figure 12] (Pendleton, 1940). The evidence is also found in Pulau Upeh, Melaka where it had been cut smoothly about more than 2 inches, parallel to the usage of pickaxe (Figure 13). Whereas, for laterite formed in a soil, the characteristic of laterite is ranging depend on their depth. Pendleton (1952) suggested on digging up to approximately about 50cm in Ceylon and few centimetres to 180cm from the top of a 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 compressive strength and density of laterite stones (Kasturba et al., 2007). It is proven that the usage of laterite stones for the heritage buildings in Melaka that is sourced from the seacoast area with considerable dimensions is a part of the valuable knowledge of Portuguese's stonemason thread. The maximum thickness is also found near to seacoast area (water access) in Malaysia (i.e. Tanjung Dahan and Pulau Upeh). On top, 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).



**Figure 11: Cutting processes of laterite stone in Prachiburi, Thailand for Bastion Middelburg**  
Source: JWN (2008)



**Figure 12: Manually cut laterite using pickaxe in Chanburi, Thailand**  
Source: Pendleton (1940)



**Figure 13: Laterite stone-cutting scar in Pulau Upeh, Melaka**  
Source: Author (2017)

To cater the demand of maintenance and repair that tightens with a certain specification of size, 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 seam 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). In this section, ideally, the process of extraction and quarrying of laterite stones associated with the energy usage (carbon content) is not the main impetus of CO<sub>2</sub> 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 a 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 CO<sub>2</sub> emissions on extraction and quarrying. Therefore, the CO<sub>2</sub> emissions for stone replacement are found dominated by transportation process. However, using a locally sourced material may reduce CO<sub>2</sub> emissions. In the case of locally sourced from old quarry of Pulau Upeh, based on current seawater, there are two important considerations need to be taken into account, which is suitable timeframe to deal with water-tide, i.e. the low water tide, large amount of laterite stones will be fully exposed to allows more stone to be extracted and also appropriate transportation modes such as boat and commercial transport to the jetty and site. In practice, however, the appointed conservator and experts in stonemason also plays a vital role in succeeding the implementation of sensitive repair of laterite stone replacement.

## Conclusion

The 'Green Maintenance' concept and methodology prioritised the importance of reducing the 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 a long run through the calculation of EMI. In another 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 urged the need of out-sourcing of material from a foreign country, due to the limited resourcing location of laterite stones. Subsequently, this process had contributed to a large number of CO<sub>2</sub> emissions emitted 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, Pranchiburi and Pulau Upeh by developing a process map of stone replacement. The indication showed that CO<sub>2</sub> emissions of stone replacement are only contributed through the usage of the mechanised tool in primary cutting and transportations process. Proven that, locally sourced material and manually handled in primary cutting will contribute to very low of CO<sub>2</sub> emissions. Development of process map of extraction of laterite stone within 'cradle-to-site' in this paper needs to be further tested using the mathematical equation as previous findings postulated that stone replacement emitted a high number of CO<sub>2</sub> emission and it contradictory with the current works of literature. However, it is undeniable, 'Green Maintenance' concept and methodology that envisioned to reduce the environmental impact had allowed a greater analysis of other dimensions (conservation philosophy and cost) to become more realistic in the decision-making process.

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