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Green Maintenance for Heritage Buildings: Low Carbon Repair Appraisal Approach on Laterite Stones

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Sustainability is commonly encapsulated economic, environmental and societal domains. Low carbon repair for heritage buildings also conforms to these broad domains, without exception. Recently, there is emergence of environmental consideration in low carbon repair appraisal for heritage buildings that become increasingly important and this paper supports this growing area. Primarily, this paper gives insight on how 'Green Maintenance' concept and methodology practically determine and ultimately substantiate on appraisal on low carbon repair for laterite stone of heritage buildings located at historical city of Melaka, Malaysia. Subsequently, this paper also provides highlights on common techniques and material for laterite stone repair of the selected heritage buildings. It is discovered that the replacement is considered as the most sustainable repair technique based on relationship between high longevity and low embodied carbon expenditure, in terms of generated Environmental Maintenance Impact (EMI) of 'Green Maintenance' modeling. More importantly, the model gives preference towards repair technique of laterite stone that has the highest longevity of repair, with the lowest maintenance intervention i.e. low carbon repair. Significantly, the quantification of EMI will allow an appraisal on low carbon repair approach based on the value of true CO_2 emissions. This can be achieved mainly through the quantification of embodied carbon expenditure expended in repair within 'cradle-to-site' boundary of Life Cycle Assessment (LCA), using formulaic expression and calculation procedures of 'Green Maintenance' Model.

1. Introduction

Sustainability and conservation of heritage buildings are inevitably inseparable which are always encountered in the activities of maintenance and repair. As maintenance and repair become the most important activity in conservation, the applicability of sustainability can be represented in terms of economic, environmental and social considerations. As such, this paper introduces 'Green Maintenance' concept and methodology as a main tenet of sustainability that call for a protection of the fabric and preserving the other capital such economy and environmental inclusively.

Generally, maintenance is the primary activity in conservation that aims to protect the fabric of the building that contains cultural significance (ICOMOS Australia, 2013). In attempting this, maintenance and repair work should be complying with conservation principles, philosophically. The principles are least intervention, like-for-like material replacement, honesty, integrity and also reversibility (Bell, 1997). The intervention that fits the philosophical framework is naturally good, high quality, most compatible to existing fabric and endures longer than insensitive, often inappropriate repairs. However, the action in maintenance and repair are always set with the budgetary factor. Comparatively, the ability to undertake repairs that complies with conservation philosophy does not always expensive but fundamentally high quality that provide the longer lasting replacement, that is seemingly worth for cost invested. In addition, it is also related to the value of building as an asset where the value will change according to the quality of maintenance and repair undertaken.

Moving forward, the investment in maintenance and repair can also produce meaningful benefit to avert environmental impact. Sullivan et al. (2010) expounded that, though heritage buildings adhere to the conservation philosophies, the level of awareness in our society upon the importance and priorities of low embodied carbon is steadily increasingly. Embodied carbon is CO_2 that released through the process of extraction, manufacturing and transportation of materials that consume a fair amount of energy in terms of electricity or fuels in maintenance and repair process. In 2010, the manufacture and transport of materials were

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accounted for more than 10 % of CO_2 emissions (English Heritage, 2007). This pinpoints that the maintenance and repair have a role in promoting the low environmental impact in term that CO_2 emissions became the main emerging factor in 'Green Maintenance' concept and methodology. Figure 1 represents the traditional accepted sustainability concept that offers a framework for evaluation of sustainability in maintenance and repair. The evaluation of invention will be based on philosophical, cost and low environmental impact. Taking everything into consideration, the interventions (repair technique) undertaken that comply with the three factors in Figure 1 will be considered as being most sustainable.

Ideally, heritage buildings can be made to be more sustainable through 'Green Maintenance'. The concept supports the development of knowledge in maintenance practice that needs a pragmatic dispersion towards sustainable which prioritizes the cultural significance not only based on cost and philosophical aspects but low environmental impact. As carbon abatement became a responsibility for each country, therefore, this concept will be positively welcomed.

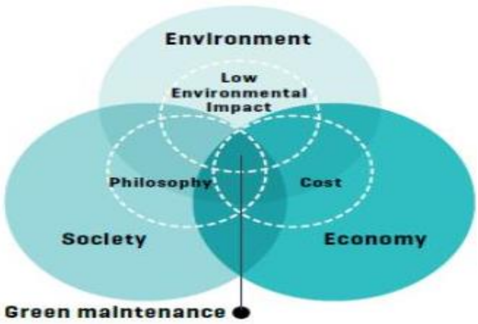

Figure 1: 'Green Maintenance' conceptual model (Forster et al., 2011)

2. 'Green Maintenance' Concept and Methodology

Essentially, the measurement of CO_2 emissions in maintenance and repair would cover the extraction of raw materials to the end of the product's lifetime (cradle-to-grave) of LCA boundaries, but in acquiring accurate result, the measurement is limited to cradle-to-site analysis. The 'Green Maintenance' sets out an insight on the relationship between maintenance and repair with CO_2 in selecting the low carbon repair for heritage buildings. Figure 2 sets out the proposition in order to understand the relationship between each intervention that are characterized by its longevity (*l*) and embodied carbon expenditure (C*e*) on the service graph condition. The downward sloping signifies the decline condition of the buildings over the life cycle of repair. Each intervention is important to keep the buildings at the optimal service condition. Hypothetically, the more frequent the maintenance intervention, the greater embodied carbon expended (Forster et al., 2013).

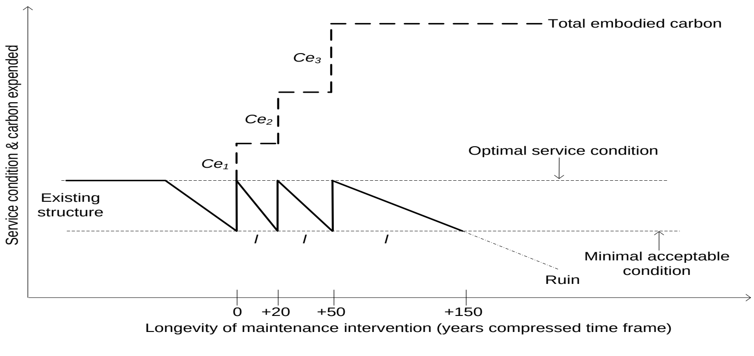

Figure 2: Relationship between longevity of repair and embodied carbon expenditure (Kayan, 2013)

Thus, 'Green Maintenance' gives the preference to the repair technique that has high longevity which subsequently incurred lesser number of repeat interventions and may incur lesser embodied carbon expenditure over the life span of the building. However, there will be a single or combination of repair techniques in a certain maintenance period in practical. Hence, high consideration with the numbers, type of repair and the embodied energy and CO_2 expended in repairs is paramount important in this evaluation. Additionally, every intervention is also influenced by other variables including material durability, degree of exposure, building detailing, quality

of repair and specification. For example, lesser durable material may not consume much energy during production, but it may require frequent replacement and resulting in higher total embodied carbon in maintenance.
The total embodied carbon expended in the maintenance over a life span of buildings has made up the 'Environmental Maintenance Impact' (EMI). Cumulative effect of maintenance denoted as *n* with each intervention has carbon impact (*Ce*) and a longevity (*l*). The total embodied carbon is illustrated in equation (1)

$$\sum_{i=1}^{n} ce_i \qquad (1)$$

2.1 Testing the 'Green Maintenance' Model: Laterite Stone Repair Techniques for Heritage Buildings

The case study was selected from heritage buildings or structure located within Melaka World UNESCO Heritage Site. Built between 16th and 18th century with historical significance from the colonials (Portuguese, Dutch and British) inheritance, they were mainly designated within Melaka Fort and constructed using laterite stone. Due to it localities, the case study consistently has weathering effects of Malaysia's typical hot and humid of tropical climate which has resulted to their consistent deterioration. This has influenced longevity of their repair.
Laterite stone of Melaka, is a ferruginous deposit of vesicular structure (deposit). This deposit is soft such; it can be cut using a spade, to be made into regular blocks when in freshly state, rapidly hardens and highly resistant to weathering, once it is exposed to the air and sun, subsequently suitable for building purpose. However, beyond the uniqueness, little research has been done for this material particularly on maintenance and repair. Nevertheless, it also demand attention in the Conservation Management Plan for Melaka UNESCO World Heritage Site regarding the appropriate treatment that closely related to materials, methodologies, techniques and workmanship.

Figure 3: Laterite stone structures of heritage buildings/structure Historical City of Melaka

In this paper, only embodied carbon expenditure expended from repair techniques of deteriorated laterite stone structure or elements of case study within Melaka World UNESCO Heritage Site were evaluated using LCA approach. Purposely, four major repair types are most common either in single or combination of repair techniques for laterite stones are tested in this study. These are stone replacement, plastic repair, repeated repointing and pinning and consolidation (Ashurt and Ashurt, 1988). Torney et al. (2014) also indicate that a number of repair options may be considered in cases of masonry deterioration, including natural stone replacement (indenting), consolidation and 'plastic' repair with mortars. Each repair technique brings a number of benefits and drawbacks relating to both technical and philosophical aspects of masonry conservation. Figure 4 shows 5 scenarios are defined for maintenance of 1m^2 of area for laterite stone over a study period of 100 y.

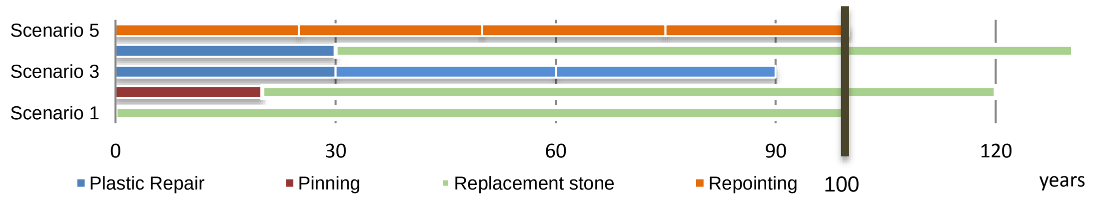

Figure 4: Repair Scenarios

2.1.1 Scenario 1: Stone Replacement

Replacement of stone is a repair involves in serious decayed stonework. It is necessary to dig out the decayed stone, replace it with the matching one. Typically, it requires cutting back of approximately 100 mm of the defective material and building in a new section of stone (Forster et al., 2011). In terms of embodied carbon, in reality, there will be limited choice for replacement stone and need to undergo some process such as quarrying, extracting, processing and transporting. It may incur high energy usage, which contributes to high embodied carbon (Hu and Wang, 2016). But, comparatively, life expectancy of 100 y may lead less maintenance intervention in a study period (Kayan, 2013).

2.1.2 Scenario 2: Pinning and consolidation, followed by stone replacement

Pinning and consolidation is a technique used to stabilize the deteriorated stone of the buildings (Forster et al., 2011). This method utilizes nylon or stainless steel dowels into hole, drilled into delaminating layers or detached section of wall and fixed in place with modified lime grouts for 20 y period. Due to its lower longevity, it requires further intervention in form of stone replacement. As previously discussed, stone replacement will last more than 100 y of study period. Hence, the EMI will be 0.8 in the study period (Forster et al., 2011)

2.1.3 Scenario 3: Repeated plastic repair

Plastic repair is a technique involved in repairing the surface of the buildings. It refers to building of decayed stonework with mortar. The decayed stone need to be cut back and the lime-based mortars are applied to surface of the stone. The longevity of repair is generally in only 30 y, later, the intervention is reapplied every 30 y periodically (3.33 times in the study period) (Kayan, 2013).

2.1.4 Scenario 4: Single plastic repair, followed by stone replacement

Similarly to scenario 3, high level of deterioration may lead to further intervention such as stone replacement. In this situation, plastic repair will be removed and the decayed stone will be removed after 30 y and replace the new stone. Similar to scenario 2, the replacement will last beyond 100 y in a study period and the EMI in this study is 0.8 (Forster et al., 2011)

2.1.5 Scenario 5: Repeated repointing

Repointing is the most common technique in every technique discussed previously. It is an option for the repair of loose open, crumbly and washed-out bedding and jointing mortar of wall. Dealing with defect and decay, repointing requires cutting out failed joint mortar and applying new mortar for finishing in order to replicate the original mortar style. The durability of repointing will depend on two factors; the mortar used and the finish profile given to the face of the joint. A normal expectation for repointing is at least 25 y which incurs 4.0 times of its EMI to the 100-y of study period (Forster et al., 2011).

3. Result and Discussion

Table 1 summarises the EMI evaluated in terms of embodied carbon expenditure for each scenario of repair over 100 y study period. The average embodied carbon associated with the repair of 1m^2 area of laterite stone structure located within Melaka World UNESCO Heritage Site, Malaysia on 'cradle-to-site' basis including both materials and transport.

Table 1: Carbon emissions associated with alternative repair scenarios undertaken 1m^2 of masonry wall

		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Stone Replacement	kg CO_2/m^2	36.4	36.4		36.4	
	Number of Intervention	1	0.8		0.7	
Pinning and Consolidation	kg CO_2/m^2		13.9			
	Number of Intervention		1			
Plastic Repair	kg CO_2/m^2			15.1	15.1	
	Number of Intervention			3.33	1	
Repointing	kg CO_2/m^2					15.1
	Number of Intervention					4
Total EMI	kg CO_2/m^2	36.4	43.0	50.3	40.6	60.4

It is important to note that sustainable repair approach of 'Green Maintenance' concept encourages higher longevity, which fewer interventions undertaken. Based on Table 1, stone replacement shows high-embodied carbon, but has the lowest EMI. In this case, replacement stone dealt with high-energy usage, subsequently contribute high-embodied carbon, but it is worth with one single intervention. Comparatively to the other techniques such as pinning and consolidation, plastic repair and repointing have low initial embodied carbon but repeating intervention in 100 y is necessary. Philosophically, replacements with a new stone block unit require removal of greater quantities of original fabric, and logically contradict to least intervention principles. However, the stone replacement could be done best by complying with the like-for-like material, honesty and it rather done once than repetitive intrusion to the fabric. Forster (2010) also opened the debate on the "trade off" situation or "retention of fabric against longevity of repair" that shows higher longevity ideally ensure longer survival and authenticity.

Even so, other prominent consideration to be included in the quantification of energy usage in the raw material process, transportation of material and manufacturing ('cradle-to-gate' of LCA boundary) and transportation of stone to building site. Firstly, in terms of calculation, material data mainly derived from Chrisna et al., (2011) and Hammond and Jones (2011). Noticeable, there is different source of power contributes to different CO_2 emissions, particularly in product or materials manufacturing. It must be emphasised that embodied carbon coefficient values from foreign data were always influenced by national differences in fuel mixes and electricity generation. Frischknecht (1998) has developed a life cycle inventory model on how different source of power generation influencing CO_2 emission in product manufacturing "national electricity mix" and "small scale gas-fired combined heat and power generation". For the purpose of this paper, primary energy sources (such as coal and electricity) were only evaluated if they are relevant. Additionally, all direct embodied carbon use from fuels and electricity at raw material extraction (embodied carbon co-efficient for quarrying, mining, manufacturing and processing) are included. In this case, embodied carbon coefficient of materials used in laterite stones repair was due to the use of energy, electricity and fuel combustion during the quarrying and processing process (cradle-to-gate). In addition, the fact of the depletion of source of laterite in Malaysia forces the conservator to import the material from Prachiburi, Thailand. Thus, this may incurred long transportation distance than locally sourced materials (limestone, sand and white cement). In term of calculation, embodied carbon expenditure for materials transportation (gate-to-site) @1.32×10^{-4} kgCO2/(kg.km) using updated 2008 CO_2 emission factors for all Heavy Good Vehicle (HGV) road freight (based on United Kingdom average vehicle loads in 2005) (IFEU, 2008; Defra/DECC, 2009) or emission factors (kg/kg.km) were selected. In calculation, 1.32 x 10-4 kgCO_2/kg.km emission of HGV road freight was used to calculate embodied carbon expended in the transportation of laterite stone structure repair materials to building sites, within 'gate-site' boundary of LCA)* distance [shortest and most direct distance travelled for repair material transportation from resourcing location to building site (in km)]. A ton km (tkm) is the distance travelled multiplied by the weight of freight carried by HGV.

In practice, transportation factor influenced by the philosophical attitude towards green repair techniques and their repair strategies (Blumberga et al., 2014). Hence, 'Green Maintenance' promotes several mechanisms such as usage of locally sources repair materials, engagement of regional companies to undertake repair work and selection of material with low embodied carbon (Kayan, 2013).

Moreover, other factor contributing to the CO_2 emissions in maintenance and repair is regarded to the area repaired. The larger the area that needs to be repaired, the higher number of interventions to be undertaken, the greater the total of embodied carbon expenditure. Hence, the consideration of repair technique needs to consider the area damage to select the best option for the certain amount of damaged area. Therefore, the total embodied carbon expended in the maintenance and repair has made up the 'environmental maintenance impact' (EMI). This is of paramount importance to select the sustainable repair technique based on low environmental impact (CO_2 emissions).

4. Conclusions

The maintenance and repair practice need a paradigm shift towards sustainability. Ultimately, 'Green Maintenance' provides a sustainable solution in selecting a repair options based on environmental point of view. It is mainly through the repair options that have low environmental impact of CO_2. This can be achieved through the quantification of embodied carbon expenditure which indicates the 'true' CO_2 emissions expended in repair techniques. The evaluation is based on potential repair technique of laterite stone for heritage buildings in Melaka. Mainly, 'Green Maintenance' gives a preference to a repair technique that has high longevity and durability, which consequently offer less maintenance intervention. Replacement of stone is considered as sustainable repair technique rather than plastic repair, repointing and consolidation/pinning. But, there are several considerations needed to be noted, such as the resourcing location and the distance between the areas that need to be repaired. However, this paper may not thorough enough to indicate the whole scenario of laterite stone repair and maintenance for heritage buildings in Melaka. Hence, this study needs a further research in developing the life cycle process of maintenance and repair for the laterite stone and test the formula (equation) given to fully adopt the concept and approach of 'Green Maintenance'. By quantification of embodied carbon expenditure (CO_2 emissions), it enables the decision makers to facilitate a deeper analysis between philosophies, cost and discuss it against carbon emission. Subsequently the ‘Green Maintenance’ approach lists the alternative options with strong justification for decision-making process, chiefly on selecting the most sustainable repair for heritage buildings.

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Reference

Ashurst J., Ashurst N., 1988, Practical Building Conservation: Stone Masonry, vol 1, Gower, Aldershot

Australia ICOMOS, 2013, The Burra Charter The Australia ICOMOS Charter for Places of Cultural Significance

Bell D., 1997, Technical Advice Note 8: The Historic Scotland Guide to International Charters, HMSO, Edinburgh

Blumberga D., Cimdiņa G., Timma L., Blumberga A., Rošā M., 2014, Green energy strategy 2050 for latvia: a pathway towards a low carbon society, Chemical Engineering Transactions, 39, 1507-1512

Crishna N., Banfill P.F.G., Goodsir S., 2011, Embodied energy and CO2 in UK dimension stone, Resources, Conservation and Recycling, 55, 1265-1273

DEFRA (Department of Environment, Food and Rural Affairs)/ DECC (Department of Energy and Climate Change), 2009, Guidelines to Defra/DECC's GHG Conversion Factors for Company Reporting, Defra/DECC, London, UK.

English Heritage, 2007, Conservation Principles, Policies and Guidance for the Sustainable Management of the Historic Environment (Second Stage Consultation), English Heritage, London, UK.

Forster A.M., 2010, Building conservation philosophy for masonry repair: part 1 – “ethics”, Structural Survey, 28, 91-107

Forster A.M., Carter K., Banfill P.F.G., Kayan B., 2011, Green maintenance For Historic Masonry Buildings: An Emerging Concept, Building Research & Information, 39, 654-664

Forster A.M., Carter K., Kayan B., 2013, Greening Maintenance. RICS Building Conservation Journal, December 2013/January 2014, 32-33

Frischknecht R., 1998, Life Cycle Inventory Analysis for Decision Making, Scope Dependent Inventory Models and Context-specific Joint Product Allocation, ETH Zürich, Switzerland

Hammond G.P., Jones C.I., 2011, Inventory of Carbon and Energy, Beta Version V2.0, Department of Mechanical Engineering, University of Bath, <www.bath.ac.uk/mecheng/sert/embodied/> accessed 10 May 2016

Hu Y.L., Wang J., 2016, Analysis on the case of green reconstruction of the existing buildings, Chemical Engineering Transactions, 51, 841-846

IFEU (Institut für Energieund Umweltforschung Heidelberg GmbH), 2008, EcoTransIT: Ecological Transport Information Tool for Worldwide Transports – Environmental Methodology and Data, IFEU, Heidelberg, Germany.

Kayan B.A., 2013, Green Maintenance for Historic Masonry Buildings: A Life Cycle Assessment Approach, Ph.D. Thesis, Heriot-Watt University, Edinburgh, Scotland, United Kingdom.

Sullivan J., Burnham M., Wang M., 2010, Energy-consumption and carbon-emission analysis of vehicle and component manufacturing, Argonne National Laboratory, Illinois, United States, DOI:10.2172/993394

Torney C., Forster M., Szadurski, Ewan M., 2014, Specialist ‘restoration mortars’ for stone elements: a comparison of the physical properties of two stone repair materials, Heritage Science, 2, 1, doi: 10.1186/2050-7445-2-1