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Review of Maintenance Strategies For Achieving Sustainable Developments In Tropical Climates

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Abstract

Buildings, like almost all physical objects degrade over time due to a combination of factors. The deterioration affects all components and parts of the building in different ways, gradually reducing the quality of the structure and adversely impacting the building's ability to effectively perform its basic functions in an environment. This paper relied on a systematic review of published literatures in reputable databases to examine how building developments and public environments can be designed in tropical climates to require minimal maintenance activities to enhance the ease of executing such activities. 39 open access published documents were reviewed. Data sieved from the publications were content analysed and descriptively presented in themes. The study identified principles and methods which can be implemented in the design of buildings with a focus on maintainability towards enhancing the development of sustainable public buildings and environments in tropical climates. The review promotes maintenance culture and emphasises increased consideration for maintenance in building design, which further helps to promote the eleventh target of the 17 Sustainable Development Goals that aims at the development of resilient, safe and sustainable communities, cities and human settlements. The paper is instructive to researchers, scholars, students of architecture and building design, as well as policy makers on issues surrounding the principles of designing for maintainability, particularly in tropical settings.

Keywords: Building Maintenance, Designing for Maintainability, Public Buildings, Sustainable Environment and Tropical Climates.

1.0 Introduction

Building maintenance is an integral part of building development operations and necessary to sustain the reliability and efficient performance of a building. Maintenance operations are used to eliminate a variety of defects and preserve the value of a building, improving the ability of the building to function as required for the benefit of the building users (Muktar, Nirmalawati, Asnudin and Nyoman, 2023). The issue of maintenance is therefore essential to the preservation of all infrastructural development. Thus, maintenance operations should be carried out on all building types as may be required (Izobo-Martins, 2014).

The reality however, is that poor building maintenance is a global challenge and a widespread problem, particularly in developing countries. Maintenance activities are a costly but necessary aspect of building and facility management throughout a building's lifespan. They can range from everyday activities like general cleaning of spaces and select surfaces in the building, to specialised planned and periodic activities in the form of renovations and wholesale replacement of building systems. In developed countries, buildings and public infrastructure are a significant source of revenue and are therefore highly valued and properly maintained, as opposed to developing countries that obtain significantly less revenue from infrastructure (Ugwu, Okafor and Nwoji, 2018).

An alternative approach to maintenance which can minimise the costs and resources required for proper maintenance is to integrate features which aid and improve maintenance activities and operations in the design of a building. Designing a building which properly pays consideration to maintenance, makes it adaptable to current functions and potential future uses (Ismail and Mohamad, 2015). This also minimises the cost and complexity of performing maintenance operations in the building's lifespan. Despite these benefits, designing for maintainability is considered a less important trade-off in conventional building design by majority of building design and construction professionals (Ismail and Mohamad, 2014). A number of studies (Fairclough, 2002: Construction 21 Report, 1999; Egan, 1998) have concluded that improvement of the maintainability of buildings will produce significant impacts in the long-term operation of buildings. However, maintainability has failed to be a key consideration for building designers.

According to Izobo-Martins, Ekhaese, and Ayo-Vaughan (2018), public buildings are vital to the development of a nation and proper planning for maintenance must be used to ensure that the buildings function efficiently and effectively. The need for maintenance in buildings is a result of wear and tear caused by environmental conditions and use of the building. In public buildings, the high volume of users commonly leads to more frequent use than in other building types, often leading to increased need for maintenance. In tropical climates, there is abundant rainfall and high humidity, as well as frequent changes in temperature with the average temperature being above 18 degrees Celsius (64 degrees Fahrenheit) (Sholanke, Pela, Pirisola, Ogunsade, and Akerele, 2020), with significant drops and rises in environmental temperature depending on the frequency of rainfall at a given period in time. Generally, the seasons in tropical climates are characterised by high temperatures, and intense and constant sunlight (Oluwatayo and Pirisola, 2021). Public buildings in tropical climates would therefore require additional maintenance considerations to function efficiently and reduce the cost of maintenance over their lifecycles and enhance their sustainability. The proper planning and execution of maintenance activities minimises the frequency and controls the severity of building defects. This therefore decreases the operating cost of the structure, and increases its sustainability. The reduced cost required to maintain public buildings means that public funds can be better utilised in creating new

developments rather than maintaining existing structures and also significantly improves the quality of the built environment thereby positively impacting the populace (Ani, 2011).

It is against this background that this paper investigated how public buildings and environments can be designed to require minimal maintenance activities to enhance the ease of executing such activities in tropical climates. The review sought to examine principles of designing for maintainability, with a view to highlighting their specific benefits in relation to the development of public buildings and environments in tropical regions. The study was guided by the following three objectives: to examine the principles for designing for maintainability; to investigate how building maintenance improves the sustainability of public buildings and environment in tropical climates; and to determine the benefits of designing for maintainability of buildings and environment in tropical climates.

The review provides insight on elements, features, systems and principles that are being incorporated into the design of buildings in tropical regions in order to improve maintainability of public facilities and environment. The paper highlights the need for increased consideration for maintenance in building design and signposts how designing for maintainability helps in achieving the eleventh target of the 17 Sustainable Development Goals, which aims to make cities and human settlements resilient, safe and sustainable. The issues raised and examined in the study are also beneficial towards the formulation of appropriate maintenance policies and regulations for the development of sustainable public buildings and environments. Additionally, the study will be useful to researchers, scholars, architects and building design professionals as an instructive document on issues relating to maintenance and designing for maintainability of buildings and environments in tropical regions.

2.0 MATERIALS AND METHODS

The study is a systematic review of published literature which is an essential scientific approach used to evaluate, summarize, and report the results and findings of a large quantity of publications about a particular subject (Green, 2005). Evidence in published works show that a number of publications (Saieh, Sotelino, Nascimento and Caiado, 2018; Emuze and Smallwood, 2013; Marhani, Jaapar, Bari and Zawawi, 2013) employed a similar approach in their studies.

In order to conduct this literature review, a 5-step process was used to guide the research activities. The steps are: formulating the research objectives; identifying relevant publications and literature towards achieving the objectives; evaluating the quality of the selected studies and retrieving data from them; analysing and summarizing data retrieved from the said studies; and interpreting and reporting the respective findings.

As the study focused on designing for maintainability in the development of buildings and environment, resource materials with relevant information on techniques, methods and principles of designing for maintainability in the construction industry were looked for and selected. The search for the relevant literature was conducted using Google Scholar search engine on the internet. The chosen documents were mostly open access publications indexed in Scopus, Web of Science or ResearchGate, selected through purposive sampling technique.

Keywords used for the internet search are: building maintenance, designing for maintainability, public buildings, sustainable environment and tropical climates. The resource materials were screened based

on their relevance to the goal of the study. The process of screening involved reading the abstracts of each publication to determine how useful they are to providing information relevant for addressing the objectives of the research. The literature selected following the screening were read and reviewed to identify design principles, techniques and methods for enhancing building maintainability and how they can be implemented in various building types, especially public environments. The literature review technique also provided the opportunity to examine the benefits of designing for maintainability and their impact on the sustainability of building projects in tropical climates. The results were presented in themes using descriptive approach.

3.0 MAINTENANCE STRATEGIES FOR ACHIEVING SUSTAINABLE DEVELOPMENTS IN TROPICAL CLIMATES

3.1 Concept of Designing for Maintainability

Maintainability is a measure of the ease and speed with which a structure or system can be restored to operational status in the event of failure or defects in a particular building component (Okandu, Akani and Brisibe, 2021). The maintainability of a structure is a key feature or characteristic which determines the possibility of restoring failed equipment, systems, or building components to their operable conditions using the appropriate procedures. This characteristic of a structure or system is dependent on the degree of consideration given to the ease of maintenance in building operations during the design stage.

For optimal performance, the design team should provide solutions to the requirements of the design brief as well as to potential challenges regarding maintenance activities to be carried out in a building (Rubaiey, Ulang and Baharum, 2014). It is most profitable for such solutions to be considered in the design stages when the design is gradually forming and there is allowance for alterations. The fragmented nature of current building design activities in which design activities are executed independently by each discipline gives little attention to maintenance considerations (Wong, Lim and Olanrewaju, 2022), therefore creating a need for maintenance activities to mitigate deficiencies in the design of buildings.

3.2 Principles of Designing for Maintainability

Designing for maintainability (DfM) is a process that is implemented in the early design stages aimed at enabling efficient maintenance operations and minimising life cycle costs without causing adverse consequences (Hin, 2021). The process of designing for maintainability is guided by the following principles:

3.2.1 Access for Maintenance: Building designs and forms are becoming increasingly complex and access to all parts of the building to carry out maintenance activities has become more challenging. It is necessary for designers to understand how all aspects of their design would impact the ability of maintenance professionals to perform maintenance activities as part of routine building operations (Building and Construction Authority, 2019).

In building design, it is important to plan for access to the various parts of the building, for inspection, cleaning, repair and replacement of building components throughout the building's lifespan. While most

interior spaces can be accessed with relative ease, designers should make increased considerations for access to the building envelope and façade in the design process, especially since incorporating access-provision features as an afterthought significantly increases the cost of installing such features (Building and Construction Authority, 2019).

The failure of a designer to properly integrate access-provision in the design stage can have a number of negative effects in the building operation. Such effects include: an increase in the risk factor for maintenance staff; reduced productivity as additional time would be required to perform inspection and maintenance tasks; the use of obtrusive façade access solutions; and potential loss of value of the structure (Abdullah, Ariff, Ismail and Kaliwon, 2017; Sivanathan, Jibril, Jivasangeetha, Thanaraju, Dodo and Shika, 2012).

3.2.2 Minimise Maintenance Interventions: The designer is responsible for detailing materials, finishes and systems that would perform optimally in their respective functions and be durable to avoid or minimise common and critical building defects. Selecting the right building materials can help improve the strength and durability of a structure and reduce maintenance costs over the building's life cycle (Sivanathan, *et al*., 2012). Poor material selection frequently causes ineffective maintenance and building defects which can be reduced by considering appropriate materials during the design stage (Chong and Low 2005, Chew and Tan 2003).

The careful selection of building materials is the easiest way to incorporate maintainability principles in buildings (Silva, Dulaimi, Ling, and Ofori, 2004). Building materials are mostly selected without due consideration to maintainability and use of scientific means (Chen, Okudan, & Riley, 2009) and this is a leading cause for increased maintenance workloads during the post-construction phase.

3.2.3 Forecast Maintenance: Forecast maintenance is a proactive approach to building maintenance that involves predicting when maintenance activities will be required and scheduling them in advance. Building designers should understand the impact of their designs and the potential maintenance works which will be required in the building's operation. The goal of forecast maintenance is to minimize downtime and maximize the lifespan of building components and systems by performing maintenance activities before they fail or cause more significant problems (Ben-Daya, Duffuaa, Knezevic and Ait-Kadi, 2009). In buildings, forecast maintenance typically involves regular inspections and assessment of building components and systems to identify potential issues and determine when maintenance activities will be needed. This may include regular inspections of the Heating, Ventilation and Air-conditioning (HVAC) systems, plumbing systems, electrical systems, roofing, and other building components.

Once potential issues have been identified, maintenance activities are scheduled in advance, often during periods of low building occupancy or when the building can be temporarily shut down to minimize disruptions. This may involve scheduling routine maintenance activities such as filter changes, lubrication and cleaning, as well as more significant repairs or replacements of building components and systems. Forecast maintenance can help building owners and managers to reduce the overall cost of maintenance by minimizing downtime and prolonging the lifespan of building components and systems (Park, Kwon and Ahn, 2019). It can also help to ensure that buildings remain safe, functional, and in compliance with building codes and regulations.

3.2.4 Enable Simple Maintenance: Maintenance activities such as replacement of building components and inspections are more easily performed in a building in which standardised and modular building components are utilised. The building designer must be knowledgeable of the availability of maintenance equipment and replacement parts in the market before specifying the use of such components in a given design (Sivanathan, *et al*., 2012). The design should feature standard sizes of components and equipment and modular units to allow interchanging of compatible parts and aid their replacement (Oodee and Owajionyi, 2020).

Contractors and subcontractors should provide access to information, specifications, and all other relevant data regarding the performance of different materials and components (Silva, Dulaimi, Ling and Ofori, 2004). Designers should therefore reference relevant documents that provide this information when making specifications for buildings, giving due consideration to the availability of these materials and products during and after the construction stage.

3.3 Impact of Maintenance on Sustainability

Maintenance plays a critical role in the sustainability of the built environment, which refers to the ability of buildings and infrastructure to meet the needs of the present without compromising the ability of future generations to meet their own needs. The amount of consideration given to maintenance is a major determinant of the sustainability of a structure or the built environment as a whole.

Proactive and well-planned maintenance increases the lifespan of buildings and infrastructure, reduces the need for frequent replacements, and prevents premature disposal of materials. This can help conserve natural resources, reduce waste, and minimize the environmental impact of building construction and operation. Additionally, well-maintained buildings and infrastructure can function more efficiently, reducing energy consumption and greenhouse gas emissions (Saniuk, Jasiulewicz, Kaczmarek and Samolejova, 2015).

Poor maintenance practices can have negative impacts on sustainability. For example, deferred maintenance or reactive maintenance can lead to premature failures, reduced lifespan of equipment and components, and increased energy consumption. This can result in higher costs, greater waste, and increased environmental impact. Additionally, poor maintenance practices can contribute to health and safety hazards, reducing the well-being of occupants and potentially leading to increased healthcare costs (Izobo-Martins, Ekhaese and Ayo-Vaughan, 2018).

Some studies have highlighted the importance of maintenance for sustainability. For instance, a study by Sherwin (2000) found that regular maintenance can reduce energy consumption in buildings by up to 40%. Another study by Othuman (2014) examined the relationship between maintenance and environmental performance in green buildings and found that proper maintenance can enhance the environmental performance of these buildings.

Consequently, maintenance plays a critical role in the sustainability of built environments. Proper maintenance practices can help conserve natural resources, reduce waste, and minimize environmental impact, while also improving the efficiency and performance of buildings and infrastructure (Youhansen, Ahmed and Laila, 2021). On the other hand, poor maintenance practices can have negative impacts on sustainability, highlighting the importance of proactive and well-planned maintenance strategies.

3.4 Benefits of Designing for Maintainability (DfM)

Designing for maintainability has several benefits that can be categorised under four broad headings namely: cost savings; sustainability; safer maintenance; and reduced downtime.

3.4.1 Cost Savings: A significant percentage of a building's life cycle costs is the cost of operation and maintenance of the structure and its parts over its lifespan. The utilisation of designing for maintainability principles enables building designs to be more optimised for cost-effective maintenance activities and processes (Kordestani, Saghatforoush, JadidolEslami and Preece, 2017).

3.4.2 Sustainability: Sustainability in building design is categorised into environmental, social, and economic sustainability. DfM minimises lifecycle costs and improves the economic sustainability of a building while also requiring reduced manpower for maintenance and operation and improving the social sustainability of a building. It also emphasises the use of durable, eco-friendly materials which reduces the operation energy in the building, as well as its carbon footprint (Baiden and Price, 2011).

3.4.3 Safer Maintenance: A number of maintenance activities require maintenance staff to work at heights and in confined spaces. DfM minimises the need for maintenance while also ensuring ease of access to all parts of the building, and therefore reduces risks to maintenance workers and potential liability to building owners (Jaafar and Othman, 2016).

3.4.4 Reduced Downtime: The use of DfM in a building design ensures that maintenance activities can be carried out with relative ease in a short period of time, allowing the building to return to its regular operations with minimal disruption due to maintenance work (Karim and Rolf, 2008).

3.5 Designing for Maintenance in Tropical Climates

Building designs vary from place to place as a result of a number of factors such as the function of the building, local (or relevant) building codes and regulations, client requirements, budget constraints, and the climatic conditions. The different climates in various parts of the world largely influence building design and implementation of design principles as the structures must properly respond to the environmental elements which act on them (Agboola, 2011). The varying intensity of precipitation and sunlight in different regions from one season to another requires buildings to be designed to be resilient to their local climatic conditions.

Environmental conditions which constitute the environment around a given structure have significant impact on the building's rate of deterioration. Some defining features of tropical climates are frequent change of temperature, abundant rainfall and high humidity. According to Chew and Tan (2003), the most frequent maintainability problem which could be encountered in such environments is staining of the exterior façade. In light of this, it is essential that building designs in the tropics implement highly durable finishes on the exterior façade and provide access features to the building envelope to perform maintenance activities. Chew and Tan (2004) explained that the maintainability of the façade of a building in the tropics is heavily dependent on the selected façade system, detailing, and the performance of materials used in the façade with respect to their durability and maintainability.

Materials should be selected depending on their durability and availability in current markets and the estimated availability in future markets (Kanniyapan, Nesan, Mohammad, Keat and Ponniah, 2019). The technical performance of materials, the chemical and mechanical properties of materials, material economy and documentation and detailing are key criteria which should be considered in selecting building materials for improving maintainability in a structure. The occurrence of design failures as a result of the use of inadequate materials has been identified as one of the largest influences on maintenance costs in the post-occupancy stages of buildings (Eizzatul, Hishamussin and Suwaibatul, 2012) and the proper selection of materials helps reduce maintenance costs during a building's lifespan. Materials for public buildings in tropical climates should be selected based on their ability to contract and expand minimally due to the constant changes in temperature observed in such region.

The designer also plays a key role in the maintainability of a building structure. According to Chandler and Lewis (2011), most professionals indicated that they give little consideration to factors affecting maintenance such as ease of access to cleaning areas, and ease of repair and replacement of building components. This in turn creates a variety of challenges which adversely impact the maintainability of a structure. This failure from the designer is caused by lack of training in building maintainability (Chandler and Lewis, 2011), the absence of building regulations to enforce designs to improve building maintenance, and the disjointed system of building design that leads to inadequate contributions from maintenance personnel on how to design to improve the ease of maintenance (Sivanathan, *et al*., 2012). The design team should incorporate designing for maintainability from the preliminary stages of design to optimally improve the durability of their designs (Nwankwo and Okpoechi, 2019).

4.0 CONCLUSION AND RECOMMENDATIONS

This paper examined the principles of designing for maintainability in building designs and discussed the impacts of maintenance on the sustainability of a building as well as the benefits of designing for maintainability through a systematic review of literature. Four principles of designing buildings for maintainability were highlighted namely: access for maintenance; minimising maintenance interventions; forecast maintenance; and enabling simple maintenance. These principles, when properly applied in building design and operation can yield a number of benefits to the design team, the client, and the society as a whole. The benefits include: cost savings, improved sustainability, allows for safer maintenance and reduction in the downtime required to repair and replace building components.

The review also signposted practices that can be adopted by building design and construction professionals to improve maintainability and reduce the cost of building operations. Alternative approaches to design which places increased value on contributions from maintenance personnel in the preliminary stages of design to better incorporate the principles of designing for maintainability in a building development (Ramadan, Khammas and Hameed, 2023), were also highlighted.

In light of the findings, the paper recommends the creation and proper enforcement of maintenance regulations which include incorporating the principles of DfM in the design of buildings and the prompt execution of maintenance activities following a comprehensive maintenance schedule for public buildings and environments. Designers should also be trained to consider maintainability in the design of buildings towards the development of a more resilient, safer and sustainable built environment, in line with the requirements of the eleventh target of the 17 Sustainable Development Goals.

The study examined principles and benefits of maintainability using a literature review approach that relied on only open access publications and literature sourced from specific databases. This is recognised as a limitation of the study. Nevertheless, this does not in any way diminish the benefits of the research which includes: promoting maintenance culture in the development of buildings and environment; and articulating the principles of designing for maintainability from different literatures into a single study, thereby providing a comprehensive document that policy makers will find useful towards formulating maintenance policies for public buildings and environments, as well as a resource material for scholars and researchers to consult, use and improve upon.

However, in view of the limitations of the research, the study also recommends that similar studies should be conducted with the literature search expanded to include closed access documents and the use of more academic data bases to source for data. Studies that will rely on primary data should also be conducted. Such studies can investigate the extent to which maintenance strategies implemented in public buildings and environment are effective in serving their purpose. Results from the studies will help to identify areas for improvements, thereby contributing to efforts towards the development of sustainable environments.

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