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Review

Towards Digital Twin Maintenance Management of Health Facilities in Nigeria: The Need for Maintenance Documentation

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Abstract: The COVID-19 pandemic that recently broke forth revealed the waning state of a considerable number of healthcare facilities, especially in unindustrialized territories. This is of great concern, and it has become pertinent to identify determinants of efficient maintenance management in developing countries. There is an inefficient maintenance management of hospital buildings due to a low level of maintenance documentation, which otherwise would have facilitated the adoption of digital twin (DT) technology. The existing maintenance management frameworks and models have not explored and evaluated maintenance documentation as an all-inclusive construct. Hence, this study was aimed at emphasizing the significance of maintenance documentation for its adoption as one of the main determinants of efficient maintenance management, with a view to attaining the DT maintenance management of hospital buildings in Nigeria. After a theoretical review on existing studies around documentation, the software documentation concept was used to conceptualise this observed gap in maintenance management models for public hospital buildings in developing countries. This critical review, which forms part of an ongoing study, asserts that maintenance documentation is a major construct for efficient maintenance management and a prerequisite for the adoption of DT in the management of healthcare constructed facilities in developing countries.

Keywords: digital twin; maintenance management; hospital buildings; health sector; documentation

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1. Introduction

The need for the adequate and effective maintenance of structures and other facilities using digital information technologies has become a great necessity in the global scene. It was asserted by [1] that maintenance is the combination of all technical, administrative, and managerial actions taken within the lifecycle of an item with the intent to keep it in or restore it to a state in which it can accomplish the requisite purpose and function. This means that maintenance is crucial to the efficient productivity and sustainability of different organizations' facilities. Prior to this era, maintenance has been believed to only be an expenditure account system used to monitor direct costs, which may be associated with the overall period of the mandatory shutdown of facilities [2]; however, such views have begun to change in the present times as maintenance is being regarded as a key sponsor of organizations' efficiency, delivery, and profitability [3]. The authors of [4] argued that a serious task is laid on maintenance managers to explore every opportunity that will lead to an improvement of profitability and performance following failures in organizations. In view of this, it has become necessary to inculcate technological processes in managing maintenance works in order to increase the productivity and sustainability of the processes and the facilities at large.

There has always existed a global problem on the attitude and culture towards building maintenance [5], and the COVID-19 pandemic that recently broke forth revealed the waning state of a considerable number of healthcare facilities, especially in unindustrialized territories. One study [6] asserted that public hospitals are challenged with exclusive issues that impend their relevance and survival. After conducting an assessment of the history, features, and organization of public hospitals, it was clear that these institutions by their makeup lack the capability to compete in an economy that is market-driven. It was explained by the authors of [7] that healthcare facilities are the most complex and difficult facilities to manage or maintain; this is due to the multifaceted nature of the buildings, the criticality of the electrical and mechanical systems, and maintenance budget challenges [8]. Hence, it has become critical to note that the need for an efficient management of public hospital buildings using fourth industrial revolution (4IR) tools cannot be overemphasized in this era.

The findings in [9] revealed that the healthcare sectors in developing countries lack comprehensible policies and strategies for the adequate maintenance of hospital buildings and the performance of the facilities that would provide a good working environment and that healthcare facilities, instead, have focused on the core business of rendering clinical services in hospitals. Consequently, the health sector's built environment and facilities in a number of developing countries are faced with structural discrepancies and poor service delivery resulting in unsanitary healthcare environments and associated hospital-acquired infections [10]. Could these observed issues be a result of the absence of a more robust technological process, which has the capacity to aid the maintenance activities of the healthcare sector? This lack of efficient maintenance management can be handled via the adoption of digital twin technology in the healthcare sector for managing hospital buildings.

The case of Nigeria is not commendable. Despite the fact that Nigeria has now been independent for more than five decades, it is difficult to see an apparent indication of improved performance in the infrastructure of health systems when compared with other developing nations with similar levels of economic growth [11]. One author emphasized that the enacted National Health Act of 2014 has not been able to cater for the inefficient maintenance practices in Nigerian public hospitals. The World Health Organisation also offered criticism, asserting that indicators of health outputs and services show deficit in Nigeria [12]. There is no doubt that this is of great concern, and it has become pertinent to identify the determinants that are sufficient for the efficient maintenance management of public hospital buildings in Nigeria when using the innovative industrial revolution phenomenon called digital twin technology. The author of [13] emphasized that if such issues concerning the ineffective maintenance of public hospital buildings are not handled properly, it may lead to the poor growth of parameters required for external benchmarking platforms for hospital building facilities, and Nigeria is no exception. There is no doubt that there exists in the literature the determinants or constructs of effective maintenance management such as budget, policy, personnel, and stakeholders' attitudes; however, a question arises from these constructs: are they sufficient to attain an efficient maintenance management of building facilities when using digital twin technology?

It has been observed that tracking and managing facilities efficiently is enormously complex due to the use of manual processes. It has been identified that, due to the level of IT maturity in the system, the construction professionals of maintenance units in organizations experience difficult times in carrying out their duties, thereby reducing their effectiveness and productivity. This is because there is a lack of information storage on the various facilities, and the necessary as-built models that would have aided the maintenance activities were unavailable. The authors of [14] supported this assertion that the staff of maintenance units generally use sheets of paper and field notes when carrying out their works, and these staff also manage various types of information, including 2D drawings, manuals for ancillary components, and fixtures for inspection and maintenance. Conversely, as buildings become more complex, it is not easy to make use of the traditional 2D CAD-based

information in the maintenance of buildings. This has become a challenge for achieving the efficient maintenance of buildings, especially in the health sector. However, the advent of digital twin (DT) technology is perceived to be a panacea to the challenges affecting the efficient maintenance management of constructed facilities. Adopting DT technology in building facilities is very relevant to the maintenance management of the health care sector as it will serve greatly in decision-making processes and efficient planning; it is also important to the productivity and sustainability of maintenance activities. When the DT is adopted, it will help in predicting and detecting impending problems before a failure occurs, resulting in fewer failures and user complaints, and it will help to achieve a higher level of routine maintenance activities that enable the more efficient use of staff resources in healthcare institutions.

The maintenance management of hospital building facilities has been studied extensively in countries such as the US, Australia, Canada, Israel, and the UK; a number of them have also been carried out in Malaysia. A good number of studies have been carried out on the maintenance of Nigeria's hospital buildings, with [15–18] ascertaining issues surrounding budget and policy; Ref. [18] considering the unavailability of outsourcing; [11,19,20] identifying the lack of maintenance guide for operators; and [21,22] detecting deficient budgets and a lack of maintenance policies as the foremost issues affecting satisfactory facility maintenance in hospitals in Nigeria. The authors of [23] also identified inadequate training for maintenance personnel, insufficient budgets, and a lack of scheduled maintenance programmes, as issues involving the maintenance management of buildings in public hospitals. All these studies have, in one way or another, contributed to recommendable strategies on the need for improved policies, funding, training, and outsourcing to effectively manage the building facilities of public hospitals in Nigeria. However, the studies have not distinctively emphasized the need for documentation in order to efficiently maintain public hospital buildings. The authors of [24] recommended that in order to curb the challenges facing the maintenance management of healthcare facilities, the use of real-time maintenance decision-making tools and strategies is critical, which makes the issue of documentation of foremost priority.

Considering the above, the imperative introduced by this study is based on the fact that there is inefficient maintenance management in public hospital buildings in Nigeria due to a low level of maintenance documentation, which would have facilitated the adoption of Industry 4.0 technological tools and other information exchange systems, in addition to other innumerable benefits they have to offer in bringing about the improved delivery of maintenance works. Moreover, there is a dearth of this kind of study that emphasizes the need for maintenance documentation as a roadmap to the adoption of digital twin technology for the maintenance management of public hospital buildings in Africa and, especially, in Nigeria. Hence, this paper is aimed at exploring and emphasizing the significance of maintenance documentation for its adoption as one of the main determinants of efficient maintenance management, with a view to attaining the digital twin maintenance management of public hospital buildings in Nigeria.

This paper is a critical review that considers the theoretical background of documentation and conceptualises the theoretical understanding, within the maintenance management of hospital facilities. This methodology is utilized with the understanding that a critical review goes beyond a simple listing of the articles that were found and incorporates some level of analysis and conceptual innovation [25]. A successful critical review presents, evaluates, and synthesises information from several sources. Most obviously, it can be recognised by its output, which is often expressed in a model or hypothesis rather than a solution. The resulting model can be a synthesis of different theories or schools of thought, or it might represent an entirely fresh view of the data. Hence, this study explores the maintenance management models from different sources to identify the gaps in the literature, existing studies on digital twin technology, and the concept of documentation as established in other fields of study in order to conceptualise a theoretical model and develop the model for maintenance documentation.

2. Literature Review

2.1. Digital Twin (DT) Technology

In this section, a main theme in this study, digital twin (DT) technology, is given a background overview. The review is necessary as DT is an innovative concept in the maintenance management domain; it is also a critical factor for the emphasis on the need for maintenance documentation. Dr. Michael Grieves from the University of Michigan first spotlighted DT technology; the concept can be linked to a presentation of his in 2002: Conceptual Ideal for Product Lifecycle Management (PLM) [26]. The PLM idea, which incorporates every aspect of the digital twin, holds that every system is made up of two systems: a virtual system that holds all the data pertinent to the physical system and the physical system itself, which is the real space that has always existed. Information can now travel between the physical and virtual systems thanks to the connection between these two systems [26]. The level of information exchange that exists between the physical and virtual systems shows that there is a critical need for a well-designed system of documentation. When the National Aeronautics and Space Administration (NASA) was working on the Apollo program, at least two identical space vehicles were developed to enable the mirroring or twinning of the status of the real space ship during the trip. This was the first digital twin deployment [27,28]. According to [28], NASA established the first formal definition of the term "Digital Twin", which read as follows: "an integrated multi-physics, multi-scale, and probabilistic simulation of an as-built vehicle or systems that uses the best available physical model, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin". Another study offered a condensed explanation of the term "digital twin". For instance, [29] claimed that the physical product, the virtual product, and the associated data that connect the physical and virtual products make up the idea and concept of the digital twin. Three elements—the physical space, the virtual space, and the associated data—are emphasized in the numerous definitions of a digital twin. There is no doubt that, for the smooth adoption and implementation of the digital twin technology in the maintenance management of building facilities, there is a need for a well-packaged system of documentation to take care of the associated data needed.

The DT notion is thus represented by concepts and frameworks that include these three elements, but the literature also varies in the degree of data integration. Certain virtual representations do not support automatic bidirectional data exchange, but fully integrated DTs do. Ref. [30] proposes three DT subcategories in order to resolve the notion of uncertainty. The physical object's data are manually transferred between the digital and physical versions of the digital model (DM), which has the least data integration. The status of the counterpart is unaffected directly by changes to the digital or physical object. One talks about the "Digital Shadow" when data are transferred automatically between physical and digital items (DS). This is DT in the full manifestation of the notion with full integration of the data flow in both directions between the physical and digital object. The physical parts, the virtual models, and the data that link them are thus the key DT components taken into account here. The "Data" in all of their guises provide the connection loop between the "Virtual-Physical" duality of the system. [31], for instance, believes that data moving from the "Physical" to the "Virtual" are raw and need to be processed, whereas data moving the other way are subject to various transformations and can be transformed into processed information and knowledge that is stored across digital models—with higher degrees of meaning. This finally returns as data via actuators to the "Physical". As a result, the "Physical" component gathers data from the real world and sends them for processing. In exchange, the "Virtual" component uses its built-in engineering models and AI to find out information that is used to control how the "Physical" is used on a daily basis [32]. Figure 1 below explains this in more detail.

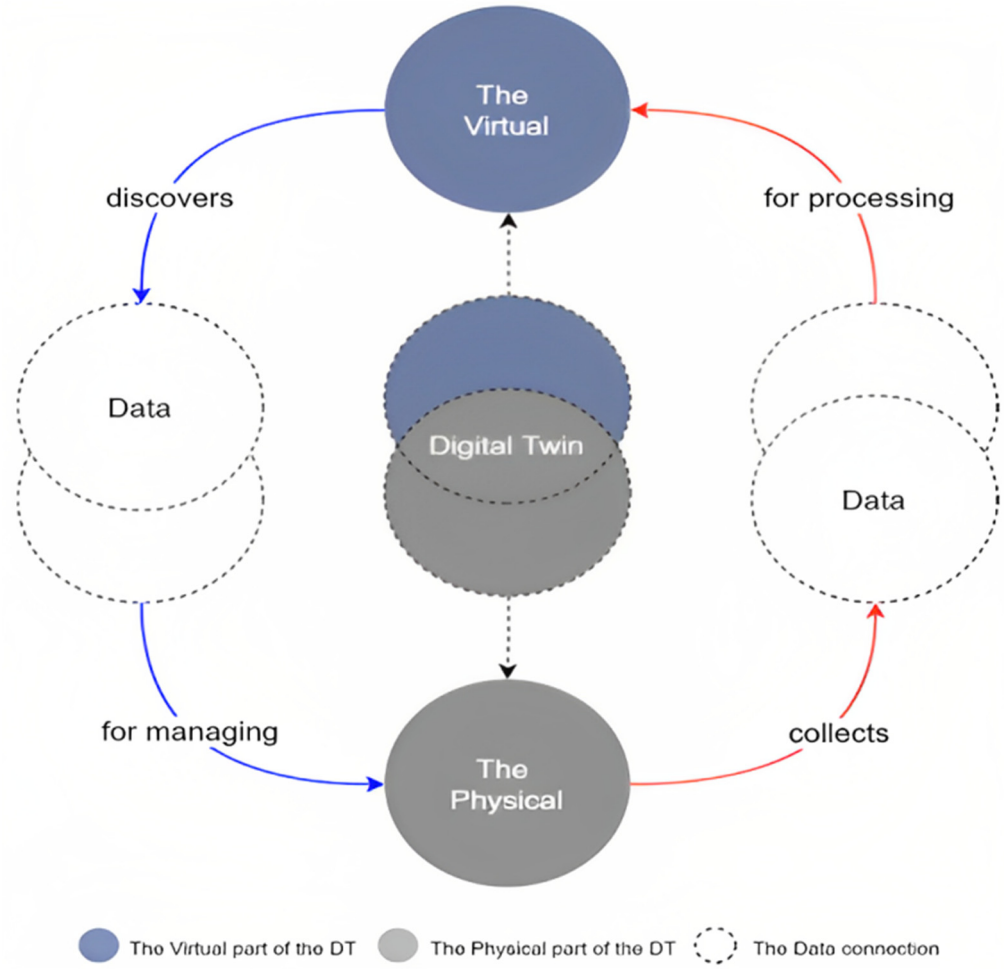

Figure 1. The Digital Twin Phenomenon. Source: Adapted with permission from Ref. [32]. 2020, Boje et al.

2.2. A Critique on Maintenance Management Research

The different maintenance management (MM) models reviewed from the existing literature are discussed below, with a view to identifying the gap that maintenance documentation must fill to attain efficient maintenance management. It also aims to assess how current realities can be improved on the subject matter, using highly improved and efficient frameworks or models.

The study in [15] presented a framework on the factors influencing the maintenance management of public healthcare buildings, and notable among them were users' attitudes and the misuse of facilities, the absence of a visible maintenance culture, some hospital management's reluctance to fund innovations, and inadequate training. This study was able to capture stakeholders' attitudes, the maintenance budget, and personnel as the constructs for maintenance management; there was no mention of issues associated with maintenance documentation. Research presented in [33] was conducted in Malaysia on poor healthcare design and how it affected the upkeep of Malaysian healthcare facilities. The authors came to the conclusion that the key determinants for effective MM should be the adequate technical know-how of the designers during the design stage, with recommendations that hospital designers should be well-known experts who are knowledgeable about the best construction materials and methods to enhance maintenance and improve the life cycle of healthcare buildings. The study narrowed its attention to just one component of the variables affecting appropriate maintenance procedures, which is maintenance personnel; the documentation that will lead to the efficient maintenance activities of the healthcare facilities was not considered. Financial aspects influencing maintenance management

in government offices were the main focus of [34], which is the maintenance budget construct. They focused their investigation on the personnel working in government offices and in maintenance. The findings demonstrated that the maintenance management has acknowledged its obligation to provide the required funds for each maintenance plan. The authors of [35] used a framework that included certain aspects influencing maintenance in residential buildings. The study found that the most important elements influencing maintenance were the use of standard materials, the design resolution factor, and good craftsmanship. These elements influence design and construction requirements because they relate to the structural and functional condition of the structure. The factor relating to stakeholders' attitudes was taken into account in the framework because it was important to understand the benefits of maintenance and that clients and maintenance contractors communicate effectively. This study also lacked emphasis on the need for maintenance documentation in the framework for effective maintenance management.

A study in [36] was conducted on the elements influencing building upkeep in government-run housing estates. Maintenance culture, money, trained maintenance employees, a stable economy, the quality of the building materials, and the engagement of other stakeholders were the aspects that went into the formulation of the model in their study. Their findings demonstrated that a shortage of cash was the most important element affecting building maintenance since finances have a huge impact on maintenance because they determine the amount of repairs that may be made. It is obvious from the study that the major constructs for effective maintenance management that were considered are stakeholders' attitudes, maintenance personnel, budget, and policy; the case of maintenance documentation was not considered. The authors of [37] researched the problem of design flaws and its impact on maintenance. Their findings demonstrated that the most important flaws complicating maintenance operations were the missing slot beneath the floor slab and the building façade. Their response was to take advantage of maintenance inputs throughout the design process to increase maintenance efficiency and reduce design flaws; all these are connected to the maintenance personnel construct. The elements influencing building maintenance of public buildings were evaluated in [38]. The policies, the money, and the stakeholders' attitudes toward maintenance were the important explanatory variables in this study. According to the findings, the most important problems affecting maintenance were a lack of cash, a failure to respond to maintenance requests, a lack of preventative maintenance, a shortage of replacement parts and components, and a lack of building maintenance standards. In fact, the lack of standards gives a clear indication that there is little or no consideration of documentation. The study in [39] used design and construction requirements as primary determinants to MM; the authors claimed that the majority of building flaws were due to poor design and construction, which increased the need for maintenance. The study came to the conclusion that maintenance professionals ought to be involved from the beginning of planning.

The authors of [40] based their framework on the elements that influence the decision to perform maintenance practices on buildings, including design sufficiency, proper use of the building after completion, accessibility to skilled labour for maintenance operations, and a strong financial foundation for maintenance work. The study reaffirmed the need for maintenance to be considered during the design process, the use of high-quality materials during building, and the need for governments to promote maintenance knowledge. This suggests that key factors affecting maintenance management in the framework include the needs of the design phase, maintenance personnel, and stakeholders' attitudes; the importance of maintenance documentation was not discussed. The elements influencing upkeep in public and private housing facilities were evaluated in [41]. Environmental considerations, design and proper workmanship, original construction quality, alterations and modifications, construction supervision, building value, gradual depreciation, wear and tear, the detailing of working drawings, material specifications, cash flow analysis, user activities, shifting values and modernizations, social considerations, and the preservation of the historical background were the factors the authors took into account in their study. This

outcome reveals that design requirements, construction requirements, and stakeholders' attitudes are the variables in the study model for MM. The authors of [42] carried out a study to assess the maintenance of some public and private buildings, and the factors considered were established within design and construction requirements such as the use of tried-and-true materials such as cement, aggregate, and water. According to the study, the use of these materials in construction will result in shoddy buildings, which will require more upkeep. Hence, involving building experts in the design stage could aid in preventing such issues. In summary, these studies conducted within the health sector environment were able to present the notable constructs of personnel, budget, stakeholders' attitudes, and policy but were unable to present the niche that maintenance documentation has to fill in the process of maintenance management.

A study in [43] conducted in Nigeria outlined a number of variables needed for effective maintenance management. They mainly include qualified maintenance personnel, regular maintenance inspection, maintenance budget, quick action by maintenance staff, maintenance training and research, user knowledge of maintenance, management education, maintenance policy, establishing acceptable maintenance standards, and a user feedback system. In an effort to lower the cost of maintenance in public health facilities, the authors of [44,45] focused on a framework that took into account the usage of outsourcing via facilities management (FM). Although it has not been completely investigated in Nigeria's public healthcare facilities, it was found that users are happy with the calibre of FM services provided there. The same authors predicted that skilled and qualified maintenance staff would improve quality, reduce costs, and free up time for the organization. Ref. [23] also presented a framework for the maintenance management of facilities as a theoretical contribution to knowledge. The sub-themes that formulated the model are legislative requirements, the design and construction phases, managing the activities of the maintenance unit, the maintenance work budget, and the users' impression of maintenance management.

Considering all these models and especially those established within public healthcare facilities, the determinants for maintenance management are extracted and presented in Table 1. The studies that have been carried out on the maintenance management of facilities have been unable to consider the criticality of documentation within maintenance organizations and, especially, healthcare facilities. Hence, this study seeks to leverage this existing gap in the literature to emphasize the development and inclusion of another construct, to be domiciled in efficient maintenance management studies, and in order to attain digital twin maintenance management of public hospital buildings. This project expands on the determinants and core attributes required for a robust maintenance system within organizations.

Table 1. Key Constructs for Efficient Maintenance Management.

Variables Authors	Maintenance Personnel	Maintenance Policy	Maintenance Budget	Stakeholders' Attitudes	Maintenance Documentation
[15]	√	√	√	√	
[17]	√	√	√	√	
[33]	√				
[34]			√		
[35]				√	
[36]	√		√		
[38]		√	√	√	
[40]	√			√	
[41]				√	
[44]	√	√	√		
[43]	√	√	√	√	
[23]	√	√	√	√	

Source: Author's Compilation, 2022. "√" is used to indicate a variable's discussion by an author.

3. Theoretical Background on Documentation

The consideration of the identified gap was based on the assessment of the existing constructs and on the fact that digital twin usage will not be possible in the absence of adequate maintenance documentation. Documentation is a subject matter that has not been broadly discussed in construction and maintenance studies; however, the social sciences, organization studies, science and technology studies, and library and information science have all long examined it. Hence, the subject matter of maintenance documentation is conceptualised from any of these fields that have carried out critical studies on it.

A long-standing issue in librarianship [46,47] as well as the ethnographic studies of science and engineering laboratories is the varied effort around documentation [48]. Researchers have addressed how employees utilize various document genres, such as records, forms, interoffice memos, and e-mails, to "achieve and coordinate their day-to-day practical actions" in studies of workplaces and formal organizations [49], p. 12. This expressly indicates that there is a need to carry out studies within the construction industry domain on the critical need for documentation in order to achieve organizational goals. For newcomers, becoming proficient at reading and writing documents in a given organization is essential to understanding how that organization functions, how its many elements interact with one another, and how and by whom decisions are made [50,51]. According to [52], academics have discussed the significance of documents in both collaborating to complete tasks and maintaining an organization's structure using frameworks including distributed cognition, activity theory, actor–network theory, coordination theory [53], and practice theory [54]. There is no doubt that the sustainability of maintenance practices will be ensured by the engagement of maintenance documentation.

Both symbolic interactionist theories [55] and ethnomethodology [56] place an emphasis on how individuals create and uphold social institutions via verbal and written descriptions. People often communicate their understandings and intentions to others with written documents. In a famous example of an infrastructure paradox, documentation work is both an essential component of an organization's operations and a frequently disregarded type of unseen work [57]. Many studies have been conducted in hospital settings, for instance, exploring how various systems and methods for keeping patient records mediate relationships between patients, nurses, technicians, and doctors [58,59]. For the fact that documentation has been a matter of emphasis in the well-being of patients in the healthcare sector of economies; it becomes critical to emphasize such phenomenon in the well-being of building facilities within the healthcare sector.

Documentation is an eminent phenomenon in the software world as well; in fact, it has a well-grounded origin and implementation in software systems. The majority of documents that are shared within organizations belong to a more distinct genre than software documentation, which is why scholars from these theoretical traditions frequently study it. Discussions of software documentation frequently centre on issues such as instruction or usability. For a long time, experts in domains such as technical communication have concentrated on the best ways to develop user-friendly documents that describe a product's features and functionalities [60,61]. There is no denying that documentation frequently plays important roles in a project's internal operations and serves as one of the main channels for communication between those that work on a project and those outside the core team. For instance, the authors of [62] studied 'agile' software development firms, in which rapid iteration is preferred over the kinds of in-depth textual planning documents that are more typical in classical 'waterfall' software engineering. A long line of research has concentrated on the role of software documentation in professional firms that develop software for clients. They discovered that these companies still utilize textual artefacts to organize and plan software development, but they do so in a very different way than many agile proponents do [63]. This is very much in line with the main theme of this study—digital twin usage. It is a concept domiciled within the information and communication technology (ICT) sector, which requires adequate documentation for its actualisation in a real-life setting.

The Otlet concept was the foundational idea for documentation, which grew epistemologically from it. The International Institute of Bibliography (IIB), founded in 1895 in Belgium, and the Universal Bibliographic Repertory (UBR), whose project was proposed in the same year and reached 16 million cards in 1934, were both mentored by the lawyers Paul Otlet (1868–1944) and Henri La Fontaine (1854–1943). In 1903, Otlet used the term "documentation" to describe the process of making papers or references available to those who require the information they may contain. The article was titled *Les sciences bibliographiques et la documentation* [64,65]. The author took into account the body of knowledge found in the bibliographic sciences and defined documentation as the production, material fabrication, distribution, listing, statistics, conservation, and utilization of information, which includes compilation, printing, publishing, bookselling, bibliography, and librarianship. Otlet considered archives, maps, plans, ideograms, schematics, drawings and their reproductions, and pictures of actual items, among other things, to be documents in addition to books and manuscripts [64,65]. In the maintenance setting, emphasis has to be given to the availability of all 2D/3D drawings/models, early warning charts, archives of components' mean time before failure, and all other documents that will aid in the roadmap to the application of digital twin technology for the maintenance management of public hospital buildings in developing countries.

Documentation is the process of locating, gathering, and making accessible to the public existing records that have permanent historical worth, such as correspondence, computer files, pictures, etc. [66]. To fill in any gaps in the historical record or to provide context for existing ones, documentation may also entail the creation of new records; for this reason, keeping track of maintenance history in logbooks and information databases is essential. To complete a set of family papers or the archives of an organization, for instance, an oral history interview may be recorded, similarly to how a photograph of a person or a building or a film of a public event can add context to written material or communicate a part of the story that is not captured in the records [66]. Any communicable material, including text, audio, video, CDs, and DVDs, as well as their combinations, may be used as documentation to define certain features of a product, system, or process. In the information age of today, the term is widely used to refer to engineering or software documentation, which typically includes printed books or computer-readable files that describe the components and structure or, alternatively, the functionality of a system or product [67]. The importance of documentation cannot be overstated because decisions about individual lives, organizations and businesses, and governments at all levels are made today and will be made in the future based on the understanding (or lack thereof) of the past. Access to the historical record enables organizations, systems, and structures to make better-informed decisions. The relationships and dealings with others are based on the knowledge and perceptions of their stories and histories. The historical record gives access to the raw materials of history; it enables clarity in stories, and these stories to be presented more fully and accurately.

4. Conceptualisation of the Documentation Framework

This section of the study is conceptually and contextually based on one of the areas that the subject matter of documentation has been well applied, as discussed above. It is the software documentation aspect; it is made up of process and product documentation [67]. Documents that detail the creation and upkeep of a system are referred to as process documentation. Process documentation includes timetables, organizational and project standards, quality documents for processes, and plans. The product that is being created is described in the product documentation. User documentation provides a product description that is focused on system users, as opposed to system documentation, which defines the product from the perspective of the engineers creating and maintaining the system [67,68]. Figure 2 gives an illustrated view on the phenomenon.

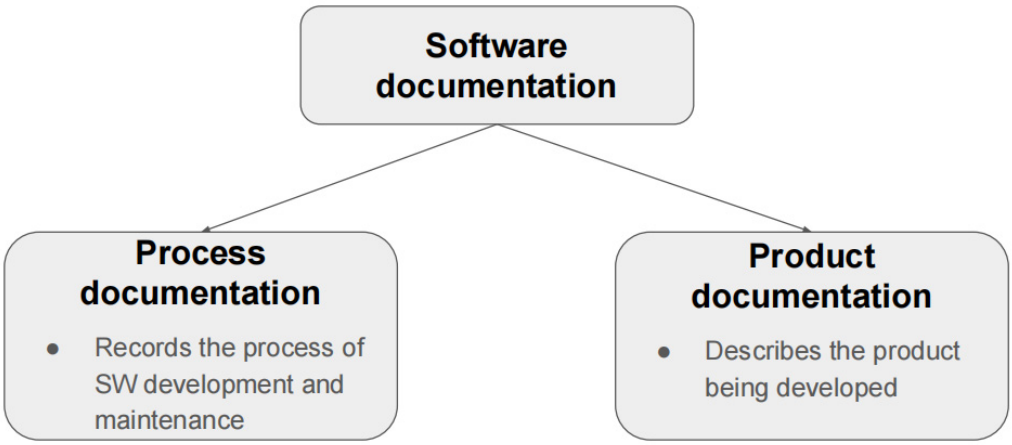

Figure 2. Types of Software Documentation. Source: Adapted from Ref [68]. 2002, Sommerville, I.

In relating this concept to this study, it is referred to as maintenance documentation. Hence, maintenance documentation is the process of the identification, collection, recording, storage, and dissemination of pertinent, historical, and current records on a constructed facility for the purpose of decision-making, the scheduling of maintenance activities, and historical value. There are a number of documents that are needed and relevant to the management of constructed facilities. They include maintenance logbooks and history, building maintenance manuals, as-built 2D drawings and 3D models, maintenance requests, activity schedule plan, stock and inventory records, early warning system charts, and maintainability analysis reports. Hence, all these documents can be conceptualised into process and product documentation. Process documents refer to those identified, collected, and recorded during the process of carrying out the maintenance works on the constructed facilities, whereas product documents refer to the actual building documents that are already available at the completion stage of the facility. Considering the above, Figure 3 shows the conceptualised model to describe the types of maintenance documentation and their attributes. The attributes shall be validated in an ongoing Delphi study, and they are as follows: the availability of building maintenance manuals, the record of used maintenance manuals, the availability of as-built 2D drawings, the preservation of as-built 2D drawings, the availability of as-built 3D models, the preservation of as-built 3D models, the availability of early warning system charts, the continuous revision of early warning system charts, the availability of maintainability analysis reports, the collection of maintenance logbooks and history, the storage of maintenance history on management software, the record of maintenance requests, the availability of a maintenance activity schedule plan, the updating of activity schedule, and stock and inventory records.

A brief operational definition of the existing major constructs of efficient maintenance management with respect to digital twin maintenance management and their relationship with the observed gap of maintenance documentation is now outlined in quick succession: Maintenance personnel refers to the staffing, training, expertise, and other activities in the maintenance unit with a view to adopting technological innovations such as digital twins in order to ensure efficient maintenance management; from Figure 3, it is obvious that all the attributes of maintenance documentation can be achieved if there are adequate, skilled, and efficient personnel. Maintenance policy refers to the laws, statutory requirements, standards, and all policies set up by the management with a view to adopting technological innovations such as digital twins in order to ensure efficient maintenance management; it is the policies set up by the health facilities that will ensure that as-built models, maintenance manuals, early warning system charts, and other attributes are in place to attain digital twin maintenance management. Maintenance budget refers to the funds, finance systems, and cost management strategies set up by the management with a view to adopting technological innovations such as digital twins in order to ensure efficient maintenance management; there is no doubt that adequate funding is required for the production

of the documents and the database systems that manage them. Stakeholders' attitudes refers to the attitude, behaviour, and values of facility management stakeholders toward regularly maintaining, protecting, and preserving public buildings, with a view to adopting technological innovations such as digital twins in order to ensure efficient maintenance management; the willingness of stakeholders to ensure that these attributes of maintenance documentation are produced, used, and preserved will be key to the efficient maintenance management of health facilities using digital twin technology.

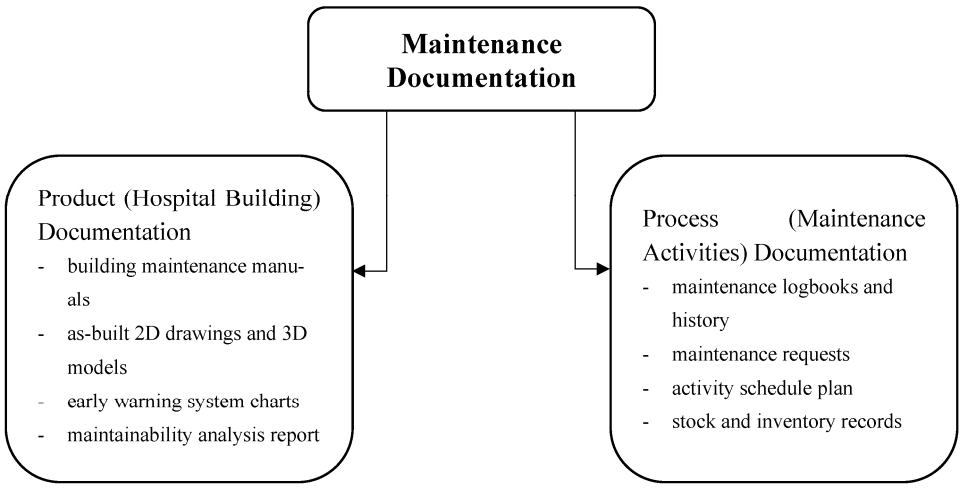

Figure 3. Conceptualised Model for Maintenance Documentation. Source: Author's Design, 2022.

There is no doubt that the need for maintenance documentation in attaining digital twin maintenance management is critical; it is a significant coordinate on the roadmap to the digitalisation of maintenance and facility management. Hence, it portrays that this gap has to be filled in knowledge and in practice for the successful implementation of digital twin maintenance management, with a view to attaining the smart and efficient management of constructed facilities in Nigeria's public hospital buildings. The availability of maintenance documentation for the management of constructed facilities will eventually become a bedrock for the development of the common data environment (CDE)—a centralised platform for storing, managing, and sharing project information among all project stakeholders. All domain-specific partial models and documents required for the planning and execution of a project are stored in the common data environment. The main responsibility is to ensure a consistent data model that satisfies the necessary standards while also acting as a platform for information exchange [69]. In order to ensure the high quality of data required for this purpose, the data management system enforces processes and techniques that all stakeholders must follow. In order to effectively manage the maturity and dependability of the delivered information, the CDE establishes quality testing methods that are carried out after each state change and assigns formal states to specific data items. As a result, the CDE provides the framework for a clear method of collaboration among all involved stakeholders [70]. The CDE's concentration of data storage lowers the possibility of data redundancy and guarantees constant access to the most recent data. Additionally, the CDE increases the rate of information reuse, streamlines the collection of model data, and acts as a central repository for documentation [69,70]. This implies that the smooth usage of digitalization concepts and digital technologies can only be made possible in developing economies, such as Nigeria, if the attributes of maintenance documentation are being given adequate attention.

5. Conclusions

As a way of developing a roadmap for the adoption of digital twin maintenance management in the health sector of developing economies, this study was aimed at exploring and emphasizing the need for maintenance documentation as a main determinant for the

efficient maintenance management of public hospital buildings. The existing maintenance management frameworks and models have not explored the possibilities and opportunities that exist in the determinant called maintenance documentation for efficient maintenance activities. Considering how the construction sector is seen generally in underdeveloped nations, especially in Nigeria, maintenance works are still lagging behind on the use of technological processes for the efficient management of buildings and other facilities. In order to attain this, an inclusive point that cannot be neglected on the roadmap is the concept of maintenance documentation. This article addresses the observed gap in maintenance management research with respect to hospital buildings. Thegap have not been evaluated as all-inclusive construct in previous models, although they have been mentioned in the discussion of the previously reviewed models but only as a distinct variable. This observed gap constitutes the additional new construct of the conceptualised framework for an ongoing study, aimed at developing a digital twin maintenance management model for public hospital buildings in developing countries, with Nigeria as a case study. The identified gap is discussed in relation to how digital twin maintenance management can be obtained for sustainable building facilities. This review forms part of an ongoing study, and the validation of the attributes of maintenance documentation will be carried out among maintenance experts to ascertain the relevance and inclusion of this construct in the maintenance management domain of developing countries. There is no doubt that the use of digital twin (DT) technology can enhance efficiency in carrying out maintenance activities, reduce the downtime of facilities, improve cost savings from the perspective of lifecycle evaluation, and improve the quality of constructed facilities; hence, there is a need for adequate documentation in order to attain the aforementioned outcomes and benefits of DT. This article, therefore, asserts that maintenance documentation is a major construct for efficient maintenance management and a prerequisite for the adoption of DT in the management of healthcare constructed facilities in developing countries.

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