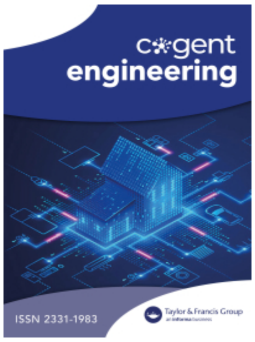


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# Exploring radio frequency identification tools for sustainable construction projects: a hybrid structural equation modeling and deep neural network approaches

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**ABSTRACT**

The wireless use of radio frequency waves for data acquisition and transfer is known as Radio Frequency Identification (RFID). RFID-based systems have been applied in various fields, including building construction and maintenance. This study aims to evaluate the RFID tools for realizing the sustainability of construction projects. The literature was reviewed to obtain secondary data, complemented by a quantitative method involving the administration of a questionnaire to 107 experts in Nigeria using a random sampling method. It was followed by data analysis using the Exploratory Factor Analysis (EFA) approach. Finally, the structural equation modeling-artificial neural network model was applied to prioritize the major constructs. The EFA results demonstrated that RFID deployment areas may be divided into two main categories: hardware and system. The results affirmed the effectiveness of the system tools for RFID implementation in the building industry. Additionally, the hybrid model revealed that system and hardware predictors rank first and second in the RFID implementation areas. The outcomes of this study are important to understanding tools and methodologies related to the fuzziness of RFID for prospective workforces. Furthermore, it is envisaged that the identified RFID tools would enhance the sustainability of building projects. This study lays the foundation for the enhancement of decision-making in building projects. Although these studies have been confined to Nigeria, the findings apply to other developing countries, especially those with similar construction processes and operations.

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## 1. Introduction

The building industry comprises various interrelated activities and components that impact society's environment and influence communities throughout the project's lifecycle (Oke et al., 2021). Estimates show that construction projects are responsible for 30% of greenhouse gas releases and 40% of energy production (Sbci, 2009). These figures underscore the significant environmental impact of the construction sector, emphasizing the urgent need for sustainable practices to mitigate these effects. Sustainable construction aims to minimize the negative environmental impacts of buildings by enhancing energy efficiency, using sustainable and recyclable materials, and reducing waste throughout the entire lifecycle of a building.

In developing countries, there are numerous obstacles to achieving sustainable construction. Although these countries are experiencing fast expansion, the question of whether the construction sector incorporates a critical role in guaranteeing

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basic living principles is yet to be fully addressed (Durdyev et al., 2018). Sustainable construction in these regions is often hindered by factors such as lack of awareness, limited access to sustainable materials and technologies, and economic constraints. Additionally, a shift from conventional construction techniques and an increased focus on long-term environmental and economic benefits are necessary for the adoption of sustainable practices.

According to Beach et al. (2013), the building industry is a notably decentralized, project-oriented, and data-demanding market. Throughout the lifespan of its properties, it necessitates massive data processing and exchanges and relies on various organizational needs and building professionals. Modern wireless technologies, such as Radio Frequency Identification (RFID), have moved past anonymity and toward traditional applications that facilitate rapid handling of materials and manufacturing items (Want, 2006). A radio transponder, transmitter, and receiver make up a standard RFID system. When activated by an electromagnetic grilling pulse from an adjacent RFID detector, the tag transmits numerical information, typically a detection catalog number, back to the reader (Marwedel & Engel, 2016). Although RFID has existed for many decades, it has recently garnered attention due to lower costs and increased capability, prompting businesses to reconsider its potential benefits. Unlike earlier barcode technology, RFID enables remote identification and does not need a direct line of sight to function (Oke et al., 2023b).

In the context of building projects, RFID can be utilized in the planning and design phases (Torrent & Caldas, 2009) and applied to monitoring ongoing and off-site activities within the construction site. Despite the extensive literature outlining RFID's advantages, there has been insufficient effort to maximize RFID advantages within the building industry in emerging countries. Moreover, RFID applications in real-life building activities are still limited, despite the need for this technology. This indicates that this advanced technology is not yet widely promoted within the building industry (Wang, 2008).

RFID research is crucial for sustainable construction because of its ability to transform the sector by increasing productivity, reducing waste, and boosting project management (Waqar et al., 2023). By enabling real-time tracking and data collection, RFID could significantly boost the sustainability of building projects, reducing their environmental footprint and optimizing resource utilization (Teizer et al., 2020). RFID technology can enhance material management, ensure accurate tracking of resources, and improve labor efficiency, all of which are critical for sustainable construction practices (Kasim et al., 2013). Furthermore, RFID can support the documentation and monitoring of sustainable practices, providing verifiable data that can be used to ensure compliance with environmental standards and regulations (Björk et al., 2011).

The conceivable reasons for this limited adoption are numerous. Project managers might be familiar with the potential benefits of RFID adoption in the building process. However, various ethical, financial, and technical hurdles might hinder its broader adoption in this industry (Chin et al., 2008). Therefore, our study aims to examine the relevant tools regarding RFID adoption in Nigeria's construction sector. Thus, the research question is, 'What are the tools that can influence RFID adoption in Nigeria's construction industry?' This research is expected to help stakeholders understand practical building schemes for RFID implementation in Nigeria and other developing countries. Consequently, the research methodology is presented in the following sections after a review of pertinent literature. The findings are labeled and discussed within the framework of available literature. Major findings and prospective recommendations are presented in the conclusion section.

## 2. Literature review

### *2.1. RFID technology*

RFID comprises a tag, reader, and middleware for sophisticated data analysis, making it useful for a wide range of applications. Because of the nature of the system, there are several issues with employing the passive tags, most notably the number of inaccurate readings in the raw data (Chen & Aini, 2020). RFID integrated two technologies and was first applied during the World War II era. Alexanderson invented continuous wave radio generation in 1906, which was the first technological advancement. The second technological innovation was the radar, which was invented in 1922 and had widespread use during World War II (Landt, 2005). RFID was used in the war to discriminate between enemy and allied aircraft. Regretfully, technological advancements have not allowed for the full realization of RFID technology's potential (Stockman, 1948).

Conway (2001) reported that RFID research was carried out in both the academic community and military aircraft divisions that were trying to develop foe and identification friend equipment during the 1950s. Sensormatic and item surveillance, which included an RFID tag security system that merely stored an 'on and off' command, did not come into existence until the late 1960s. Its function was to prevent theft in retail establishments. Throughout the 1970s, RFID was primarily focused on automating industries and tracking cars and animals. The first road toll with RFID integration was finally built in Norway in 1978 as a result of this technology's recognition. Later on, it was used in many more locations around the world. RFID was included in people's daily lives around 1990.

### 2.2. RFID tools and sustainable building projects

The concerns related to sustainability have been the focus of many studies. The introduction of the sustainability concept in the construction sector has explored precise techniques to infuse this idea into the prevailing operating systems. Businesses' pursuit of environmental protection and defining public accountability ethics could increase the application of RFID as an important tactical stage. Introducing RFID in the building execution will promote the development of viable building partners, which could facilitate teamwork compared to outdated techniques. The application of RFID technologies facilitates data access, storage, and real-time data development.

Small and medium-sized enterprises can conduct their essential, sustainable, and cost-effective business thanks to RFID. Businesses attain efficiency in enhancing commercial worth over time by creating a functioning business model (Jabłoński & Jabłoński, 2016). Usually, the entire resources - effort and time - go toward the information technology unit. Therefore, enterprises whose major product is not based on information technology do not need to worry about modernizing or conserving their information system. Rather, in order to improve their functioning and competitiveness, businesses should prioritize their core competency. On the other hand, it needs to push firms to be more creative and develop fresh approaches to managing commercial enterprises (Tehrani & Shirazi, 2014). The RFID adoption expedites enterprises' productivity while reducing waste of resources. Focusing on their primary job rather than incidental activities makes them more economical and improves their productivity and operational performance. The RFID tools in the building industry are summarized in Table 1.

**Table 1.** RFID tools.

| Code | Variables | (Want, 2006) | (Domdouzis et al., 2007) | (Wang, 2008) | (Chin et al., 2008) | (Chen & Aini, 2020) | (Landt, 2005) | (Sardroud, 2012) | (Zebra, 2002) | (Hassan & Chatterjee, 2006) | (Srivastava, 2005) | (Song et al., 2007) | (Cai et al., 2014) | (Kaur et al., 2011) | (Kim et al., 2007) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | RFID reader | | | | | | | | | | | | | | |
| T2 | RFID antenna | | | | | | | | | | | | | | |
| T3 | RFID tag or transponder | | | | | | | | | | | | | | |
| T4 | Host computer | | | | | | | | | | | | | | |
| T5 | Databases | √ | | | | | | | | | | | | | |
| T6 | Controller | | | | | | | | | | | | | | |
| T7 | Firmware | | | | | | | | | | | | | | |
| T8 | Application software | | | | | √ | | | √ | | | | | | |
| T9 | Middleware | | √ | | | | | √ | | | | | | | |
| T10 | Battery | | | | | | | | | | √ | | | | |
| T11 | Interrogator | | | | | | | | √ | | | | | | |
| T12 | Microchip | | | | | | | | | | √ | | | | |

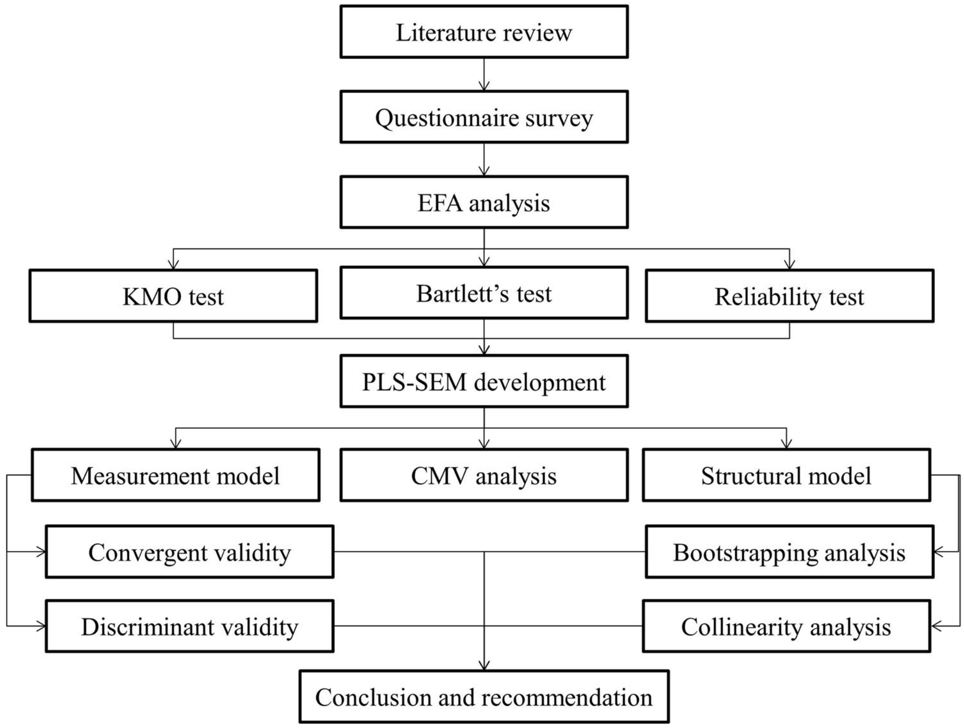


Figure 1. Research flowchart.

## 3. Research design and methods

This study aims to improve the efficient delivery of the building sector in Nigeria by identifying the RFID application tools. The phases of the study are presented in Figure 1. After reviewing the existing literature, the RFID tools were identified and measured using questionnaire surveys. The use of questionnaires helped in assessing several aspects, including (a) business standards, attitudes, and perceptions, and (b) the connection between elements and principal cause-and-effect relationships (Saunders et al., 2007). Furthermore, the impact of significant RFID tools was evaluated using a quantitative data collection approach with closed-ended questionnaires. The positivist paradigm-based quantitative stage is concerned with the results that might result in assumptions, predictions, and ultimately, generalizations. The process outcomes of the study are clear, succinct, thorough, and repeatable.

The authors followed a skeptical approach to the creation, assessment, verification, and control of information, using a quantitative research method. There are several justifications for employing a quantitative approach:

1. Objectivity: The quantitative approach ensures objectivity by relying on numerical data and statistical analysis, reducing potential biases that can occur with qualitative methods.
2. Generalizability: The use of a larger sample size and statistical tools allows for the generalization of findings, enhancing the external validity of the study.
3. Reliability and replicability: Quantitative methods provide a structured and standardized way of data collection and analysis, making it easier to replicate the study and verify results.
4. Precision: Numerical data enables precise measurement and analysis of variables, allowing for detailed and accurate assessments of the relationships and effects of RFID tools.
5. Efficiency: Quantitative surveys can efficiently gather data from a large number of respondents, providing comprehensive insights within a relatively short timeframe.

The answers were obtained from the survey tool concerning their partaking in carrying out the task, particularly designers, engineers, builders, and quantity surveyors. In addition, managers, general builders, heavy-duty workers, special servicers, construction workforce, workers, and project location operators are all building industry stakeholders. Exploratory Factor Analysis (EFA) was used to classify the various RFID tools. The evaluation and ranking of the tools' components were conducted using hybrid Partial Least Squares-Structural Equation Modeling (PLS-SEM) and Artificial Neural Network (ANN) to supplement SEM results and forecast with higher accuracy.

### 3.1. Questionnaire survey

Various recommendations were issued to establish a questionnaire with short and straightforward questions and simple language (Bryman & Bell, 2001). The questionnaire is divided into two parts. Respondent demographics and personal information are included in Section A. Meanwhile, the questions in Section B are related to RFID tools used by groups of professionals (see appendix). The questions are written such that respondents have 20 minutes to complete their responses. In the demographic section, the questions utilized nominal and ordinal scales, which aid the respondents in making unbiased and rational decisions. In the other questions, an interval scale based on a five-point Likert scale was used, as adopted in similar previous studies (Tanko et al., 2017; Tanko et al., 2018).

With 107 replies obtained out of the 122 respondents who verbally consented to participate, the study's response rate was 87.7%. The respondents were selected based on specific criteria to ensure the reliability and relevance of the data collected. To qualify for the survey, respondents needed to have significant experience in the construction industry, with a minimum of five years of professional involvement. This criterion ensured that participants had a thorough understanding of the industry's practices, challenges, and technological advancements. Additionally, participants were expected to hold relevant professional qualifications in civil engineering, construction management, architecture, or related disciplines, ensuring they had the technical knowledge necessary to provide informed insights.

Another criterion was the respondents' involvement in managing construction projects, either in a supervisory or decision-making capacity. This experience was crucial for gathering insights into the practical applications and implications of RFID tools in project management. Furthermore, participants were expected to have at least a basic understanding of RFID technology, including its uses and benefits in the construction industry. This requirement ensured that the responses were informed and relevant to the study's objectives. Lastly, the study focused on respondents working in Nigeria to ensure that the data reflected the local context and challenges specific to the Nigerian construction industry.

Notably, objective methodological and statistical analysis should serve as the foundation for determining the appropriate sample size (Badewi, 2016). Chandio (2011) concurred that a large sample size is needed for complex statistical analyses. This implies that the sample size for each study depends on the statistical analysis method (Badewi, 2016). In this study, SEM was employed, necessitating a sufficient sample size to achieve strong statistical power and rule out other models (Bentler, 1995). In this regard, Yin (2009) recommended the sampled size somewhere above 100. Also, previous studies on construction used a sample size between 37 and 100 (Oke et al., 2024; Zamil et al., 2024).

### 3.2. Exploratory factor analysis

Confirmatory Factor Analysis (CFA) and EFA are widely used for construct validity analysis (Buniya et al., 2021). This study used the CFA to examine the main composition of several variables in a certain hypothesis. Likewise, this study also applied EFA to reduce variables to a more interpretable form with a few core structures (Kineber et al., 2021; Oke et al., 2023a). Thompson (2004) argued that Principal Component Analysis (PCA) does not require any previous hypothesis, and it is extensively used in EFA. The varimax rotation method is used as it is more suitable for factor analysis (Costello & Osborne, 2005). Hence, the 12 analyzed variables and the gathered questionnaire responses were considered appropriate for factor analysis.

### 3.3. Developing PLS-SEM model

The PLS-SEM has attracted researchers from various disciplines, particularly business and social sciences (Henseler et al., 2016). Many studies concentrating on the PLS-SEM method can be accessed from the trending social sciences citation index journals (Banihashemi et al., 2017; Lee & Hallak, 2018; Hult et al., 2018). SMART-PLS version 4.0.9 software was employed for modeling RFID tools' significance using PLS-SEM (Hair et al., 2011). The statistical analysis performed in the study includes evaluating the structural method.

#### 3.3.1. Common method variance

The common method variance is defined as a resemblance of variance related to concepts and the dimension styles of the applied tools (Podsakoff et al., 2003). Occasionally, the individual data can avert or exaggerate the extent of considered relationships and thus prompt challenges (Strandholm et al., 2004). It can be important for this study owing to the personal subjectivity of data gained from a particular source. It is crucial to consider these concerns in order to spot modifications to the regular practice. Therefore, the formal one-factor test developed by Harman in 1976 was used (Podsakoff & Organ, 1986). A single factor was drawn from the factor analysis, which characterized a substantial part of the inconsistency (Strandholm et al., 2004).

#### 3.3.2. Measurement model

The measurement model shows the association among the variables and their basic concealed composition. Convergent validity and discriminant validity are discussed in the following subsections.

***3.3.2.1. Convergent validity.*** The degree of agreement between many indicators of a comparable construct is known as convergent validity (Hulland, 1999). It is categorized as a subcategory of construct validity, and it can be measured employing three tests (Fornell & Larcker, 1981): Average Variance Extracted (AVE), composite reliability scores (Pc), and Cronbach's alpha (α). Nunnally and Bernstein (1978) proposed a Pc value of 0.7 as a strong composite consistency. Values above 0.70 and 0.60 for exploratory analysis are considered appropriate for any type of study. The most recent and accepted technique for evaluating the construct's convergent validity in the measurement model was the AVE. On the other hand, scores higher than 0.50 signify outstanding convergent validity.

***3.3.2.2. Discriminant validity.*** The discriminant validity signifies that any measurement does not identify the peculiarity recorded in the SEM and that the measured case is diagnostically exclusive (Hair et al., 2010). Campbell and Fiske (1959) contended that the correlation between indicators (or tools) is atypical of one another and should be too high for forming discriminant validity.

#### 3.3.3. Structural model

This research aims to prioritize the RFID implementation tools using SEM. Therefore, the fundamental path relation (correlation) was hypothesized between £tools and μ (RFID tools). Therefore, the correlation between μ, £, and €1 rule within the structural model can be illustrated in a linear equation (Alkilani, 2018):

$$\mu = \beta £ + €1 \tag{1}$$

Where; $\beta$ is the path coefficient linking the RFID tools construct and *€1* is the residual variance at the structural intensity. The symbols ought to be empirically significant and coincident with the metrics of the model. Validating the influence of $\beta$'s path coefficient is the main issue. Concerning the CFA, the standard errors of path coefficients were calculated using a bootstrapping technique. Based on the suggestions made by Henseler et al. (2016), it was carried out on 5000 subsamples for evaluating the study hypothesis. Two structural equation constructs were proposed for the PLS model, indicating the internal correlations of model constructs.

### 3.4. Deep neural network model

Input, hidden, and output layers make up a multilayer perceptron ANN. These layers are made up of synthetic neurons that are coupled to one another via synaptic weights. During the learning process, a non-linear activation function is used to transfer data from the input neurons to the output neurons via the hidden neurons. To achieve the intended outcome, the synaptic weights are altered throughout learning. The hidden layers will allow the error terms created at the output layers to propagate back to the input layers. During each training cycle, the error terms will be reduced, increasing the precision of the predictions. Neural networks are used in this study to prioritize the RFID implementation tools (Albahri et al., 2021; Albahri et al., 2022).

## 4. Results

### 4.1. EFA of RFID tools

This study concentrated on RFID tools for buildings in Nigeria. The adopted sampling procedure expediently obtained information from the target population. The analytical method was used due to Nigeria's large population of construction partakers. The suitable samples for EFA analyses must be 45-61 respondents. In this study, it has been acceptable and evaluated with moderately short answers. Conversely, all the appropriate statistical tests were performed.

Subsequently, numerous explicit variables for the factor correlation have been employed. The Kaiser-Meyer-Olkin (KMO) is often used to investigate factor similarities and test if correlations of parameters are least possible. Based on the retrieved data, the KMO measure of sampling adequacy requirement was met for conducting factor analysis. Similarly, it was appropriate for Barrett's Sphericity test to be extremely significant between the tools. The test revealed that a sampling method or a data set was performed using KMO = 0.815, which was appropriate for factor analysis (Sharma, 1995). The results also revealed that the p-value was below 0.05, with an estimated degree of freedom and $Chi^2$ of 66 and 552.87, respectively. In this paper, Bartlett's test (p = 0.000) implied a significant relationship within the data matrix at a 5% level, indicating the EFA suitability (Tavakol & Dennick, 2011; Tabachnick et al., 2013). The total variance explained the domains of RFID application within the building industry. The PCA revealed the existence of four components (eigenvalues >1) that explained 61.3% of the total variance.

However, results showed a sheer break after component 2. The RFID tools' rotated component matrix is presented in Table 2. There is no stringent general method for classifying the factors. In this study, each component is perceived and labeled as hardware and a system after removing the 'database' factor owing to cross-loading.

### 4.2. Common method bias

The Common Method Bias (CMB) is a particular factor analysis that has been applied to evaluate the variance of the standard method (Harman, 1976). The initial fixed variables accounted for 48% of the overall variation, implying that the CMB results were unlikely to be affected (Podsakoff & Organ, 1986).

**Table 2.** Rotated component matrix of RFID tools.

| Code | Variables | Component 1 | Component 2 |
|---|---|---|---|
| T1 | RFID reader | 0.769 | |
| T2 | RFID antenna | 0.833 | |
| T3 | RFID tag or transponder | 0.704 | |
| T4 | Host computer | | 0.730 |
| T5 | Databases | 0.454 | 0.466 |
| T6 | Controller | 0.821 | |
| T7 | Firmware | 0.812 | |
| T8 | Application software | 0.559 | |
| T9 | Middleware | 0.659 | |
| T10 | Battery | | 0.828 |
| T11 | Interrogator | | 0.613 |
| T12 | Microchip | | 0.729 |

### 4.3. Analytical model

Assessing convergent validity, discriminant validity, and internal consistency is a necessary step in evaluating measurement model. Table 3 indicates that the model constructs met the limit of Pc and $\alpha$ above 0.70 and were therefore deemed suitable (Hair et al., 2021). Moreover, the results in Table 3 revealed that all the model constructs passed the AVE threshold value of 0.5, as stated by Fornell and Larcker (1981). The model output indicated that the analytical model was internally convergent and consistent. It also suggested that the dimension variables were precisely computed for each construct and did not measure any other construct within the proposed model. There was greater outer loading between the significant variables for each model's construct. The rule of thumb is that variables having smaller external loadings of lower than 0.4 must be excluded from the model (Hair et al., 2011). As presented in Table 3, the outer loadings were greater than 0.670, indicating a great contribution to the major constructs.

According to the discriminant validity, each model's construct had factor loadings for individual variables that were higher than the loading of other variables on the other model construct by row. For each model's construct, a reasonable level of one-dimensionality may therefore be justified.

### 4.4. Verification of path model

Once the RFID tools have been defined as a formative construct, the Variable Inflation Factor (VIF) may be used to assess the collinearity between the formative elements of the model construct. The model output showed that these subdomains ensured the development of the higher-order model's construct since the VIF values were less than 3.5. Additionally,

**Table 3.** Convergent validity results.

| Constructs | Items | Outer loading | Cronbach's Alpha | Composite reliability | Average variance extracted |
|---|---|---|---|---|---|
| System | T1 | 0.772 | 0.886 | 0.911 | 0.596 |
| | T2 | 0.724 | | | |
| | T3 | 0.827 | | | |
| | T6 | 0.815 | | | |
| | T7 | 0.775 | | | |
| | T8 | 0.699 | | | |
| Hardware | T9 | 0.784 | 0.743 | 0.838 | 0.566 |
| | T4 | 0.673 | | | |
| | T10 | 0.838 | | | |
| | T11 | 0.773 | | | |
| | T12 | 0.761 | | | |

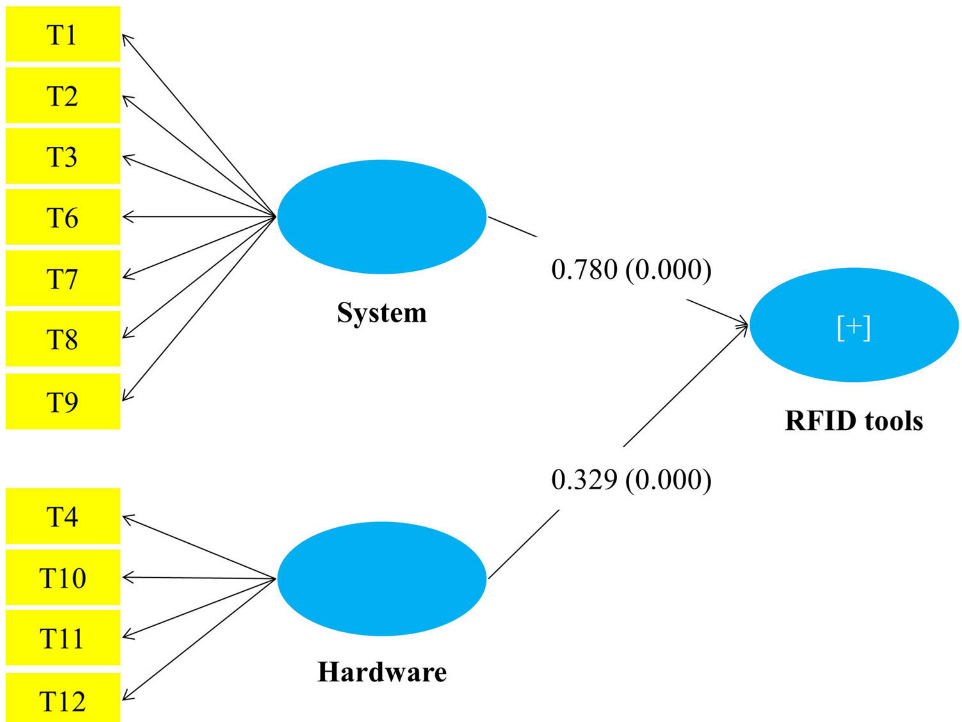


**Figure 2.** The PLS-SEM bootstrapping analysis.

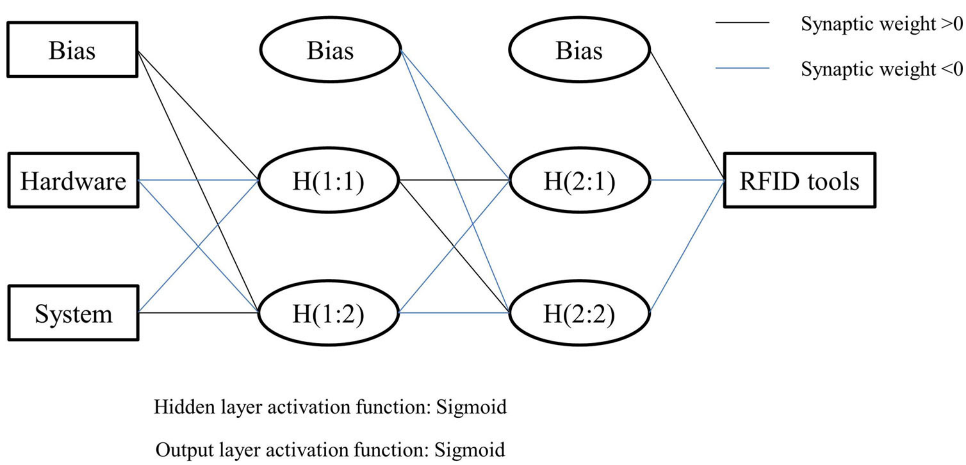


**Figure 3.** Architecture of deep learning ANN model.

a bootstrapping tool was used to predict the outcome of the path coefficients. As shown in Figure 2, the paths were statistically significant at the 0.01 level (Hulland, 1999).

### *4.5. Deep neural network analysis*

ANN was utilized to complement the PLS-SEM results in order to highlight the significance of each predictor's component. An input layer, two hidden layers, and an output layer made up the deep learning model used in this study. The input neurons were the system and hardware; while the output neurons were the RFID tools (see Figure 3). The number of hidden neuron nodes was generated automatically by the model, which employed the sigmoid function as the activation function for both the hidden and output neurons. To address the over-fitting problem, a ten-fold cross-validation strategy was applied, wherein 90% of the data were used for training and the remaining 10% for testing.

Table 4 presents the Sum of Square Error (SSE) and Root-Mean-Squared Error (RMSE) results for the ANN model. Lower error levels indicate greater forecast accuracy and vice versa. The relative weight of each input predictor is also determined using

Table 4. Error values and relative importance of inputs for SEM-ANN model.

| | Training | | | Testing | | | Output neuron: RFID tools | |
|---|---|---|---|---|---|---|---|---|
| Neural network | N | SSE | RMSE | N | SSE | RMSE | Hardware | System |
| ANN 1 | 93 | 0.072 | 0.028 | 14 | 0.106 | 0.087 | 0.331 | 0.669 |
| ANN 2 | 99 | 0.089 | 0.030 | 8 | 0.009 | 0.034 | 0.373 | 0.627 |
| ANN 3 | 97 | 0.161 | 0.041 | 10 | 0.006 | 0.024 | 0.246 | 0.754 |
| ANN 4 | 92 | 0.126 | 0.037 | 15 | 0.006 | 0.020 | 0.318 | 0.682 |
| ANN 5 | 99 | 0.141 | 0.038 | 8 | 0.002 | 0.016 | 0.358 | 0.642 |
| ANN 6 | 97 | 0.126 | 0.036 | 10 | 0.011 | 0.033 | 0.314 | 0.686 |
| ANN 7 | 94 | 0.061 | 0.025 | 13 | 0.01 | 0.028 | 0.346 | 0.654 |
| ANN 8 | 97 | 0.085 | 0.030 | 10 | 0.006 | 0.024 | 0.352 | 0.648 |
| ANN 9 | 94 | 0.057 | 0.025 | 13 | 0.001 | 0.009 | 0.324 | 0.676 |
| ANN 10 | 94 | 0.06 | 0.025 | 13 | 0.001 | 0.009 | 0.316 | 0.684 |

sensitivity analysis, as shown in Table 4. The relative significance findings indicate that system (0.672) and hardware (0.328) predictors rank first and second in the RFID implementation areas.

## 5. Discussion and Implications

### 5.1. Discussion

Building projects affect the economic and social aspects of the entire life. Therefore, creative and workable practices, measures, and resources have been applied to achieve sustainable development in the construction industry (Lee & Mwebaza, 2020). Consequently, RFID tools are important to understand the concept of project execution. These tools could enhance sustainability and construction creativity due to the application of various information technologies and constructive measures.

Conversely, no prior research has examined the tools that promote RFID adoption in third-world countries' building industries. This study attempts to lessen this gap by highlighting the RFIID tools for attaining the sustainability of building projects in Nigeria. According to the EFA results, there are four primary categories of RFID tools: data storage tools, software tools, communication tools, and platform tools. Based on the most recent SEM-ANN model findings, a discussion of these tools is given in the following sections.

#### 5.1.1. System

In RFID adoption, the importance of the 'system' is indisputable. The SEM-ANN model provides this construct with the most significant impact on RFID implementation tools. This group comprises five tools: RFID reader, RFID antenna, RFID tag or transponder, host computer, controller, firmware, application software, and middleware. The RFID reader, contingent on its performance and the utilized frequency, an RFID reader sends radio waves from one centimeter to thirty meters and beyond. A reader is required to retrieve the stored data from an RFID tag (Sardroud, 2012). It has single or multiple antennas that release radio waves and obtain signals back from the tag. When the signal is received, it issues the information to a computer device in a digital form. The RFID reader, known as the interrogator or scanner, is segregated by its characteristics, the major being mobile or stationary (Sardroud, 2012). The stationary devices are the most common types that are envisioned for tight integration in the prevailing systems. Currently, readers can concurrently read up to 100–2000 tags per second (Shoewu & Badejo, 2006). Additionally, the function of the RFID antenna is to transmit an electromagnetic field that triggers the inactive tag when it is within a given sensing range. When a passive tag is triggered, it can communicate information from its antenna to the reader's antenna, where it is processed.

However, antennas come in various designs and sizes contingent on the environment in which they are integrated into the system. The antennas establish the signals between the receiver and the transponder, and their dimension and shape determine the performance features, including the frequency range (Hassan & Chatterjee, 2006). There are three types of antennas: Low Frequency (LF), High Frequency (HF), and Ultra-High Frequency (UHF). LF is widely used due to its easy readability through materials and non-sensitivity to orientation compared to higher tags (Liard, 2003). It operates on 125/134.2 kHz (Chiaverotti et al., 2008). HF has a higher range and is less sensitive to noise, though it tends to be more dependent on the line of sight, has more power requirements, and is orientation-sensitive (Liard, 2003). It operates at 13.56 MHz and is cheaper to implement. However, a better read rate is obtained from UHF, which has many tags that could be recognizable at one time. It likewise has a better read range and three folds with higher frequency. It can read tags over 3 meters, though the range can be lowered in a wet environment.

It operates between 860-930 MHz frequencies (Srivastava, 2005).

The RFID tags can be classified into active and inactive tags. This classification is determined by the source of power transmission. The passive tags rely on a power source delivered by the energy fields of the RFID reader and might have read-only or write capabilities. In contrast, the active tags are rewritable and have an inner power source. Generally, passive tags lack longer ranges though they have a life that can outlast the object it detects. Higher memory, longer-range readings, and enhanced noise protection can be found in active tags (Ramkumar et al., 2020). Conversely, these tags are more expensive, heavier, and have a shorter life, varying from three to ten years compared to passive tags. Read-only tags are utilized for sampling detection since they can only store a small amount of data that cannot be altered. These tags might be applied to detect a package of crews or nails due to their multiple applications and are not limited to a specific item or activity (Shoewu & Badejo, 2006).

#### 5.1.2. Hardware

The second principal component includes RFID implementation tools (e.g. Google Drive and Salesforce.com). The host computer is the link between the automation system and the reader. A host computer must be designed with an RFID system. It obtains data from a single or multiple readers and checks data against its database or exchanges data with the database circulation system (Torrent & Caldas, 2009). A host computer offers all the data storage, management, analysis, and report generation abilities. The specification of the host computer includes hard disk memory requirements, computer operating system, hardware configuration, and many more.

The host computer is networked and interconnects with the control panels, which gather data on alarms and events from remote devices. Many services can be delivered by the host computer, such as refining data and supervising and synchronizing numerous readers in a single software. A battery is a source of electrical power comprising one or many electrochemical cells with external networks for firing electrical devices. Some RFID technology requires a battery to operate successfully. Likewise, the interrogator is a device that receives data from a computer file, storage device, database, or terminal. It receives the critical data for a successful implementation of the project (Kim et al., 2007).

Data is obtained from a host computer by the RFID interrogator, which gathers related data files and stores the collected data for effective and successful results. The RFID chip is a microchip that transmits a fixed identifier or serial number for a short expanse (Smith, 2008). It is a tiny chip that operates as a tracking instrument for employees and properties (Jang & Skibniewski, 2009). For example, it can monitor and access ongoing construction projects to improve efficiency and productivity.

### 5.2. Theoretical and practical implications

This study offers insightful information about the application of RFID technology in environmentally friendly building projects. It adds to the continuing discussion on sustainability and technology in the construction sector by addressing the opportunities and challenges related to RFID adoption. It also provides practical recommendations that can be implemented in developing countries to boost productivity, cut expenses, and foster environmental sustainability.

#### 5.2.1. Theoretical implications

Several theoretical implications arise from the study of RFID technology in the context of sustainable construction projects:

1. Technology and sustainability integration: The study broadens the theoretical framework of sustainable building by including cutting-edge technological tools like RFID. The potential of RFID technology to transform conventional building methods and make them more eco-friendly and productive is demonstrated by this integration. The research offers a fresh viewpoint on how technology may be used to advance sustainability objectives in the building sector by tying RFID to sustainable construction.
2. Expansion of RFID applications: The literature focuses on the expansion of RFID from military usage to commercial applications in a variety of areas, as well as its historical development and contemporary applications. The theoretical knowledge of RFID technology and its possible uses in buildings is enhanced by this historical background. By describing how RFID tools may be used successfully in construction projects, the classification of these tools into platform, communication, software, and data storage tools along with the breakdown of system components adds to the body of knowledge.

3. Framework for developing countries: The study discusses the unique opportunities and challenges associated with using RFID technology in developing countries. This approach offers a theoretical foundation for comprehending the specific challenges that these countries encounter, including financial limitations, ignorance, and restricted access to technology. Through an analysis of these variables, the study provides valuable perspectives on how developing countries might surmount these barriers to implement sustainable building techniques.

#### *5.2.2. Practical implications*

The study's practical implications are noteworthy for the building sector, especially in developing countries:

1. Enhanced resource management and efficiency: Using RFID technology can result in substantial improvements in the management and efficiency of building projects. Real-time material tracking, continual activity monitoring, and precise data collection can all contribute to waste reduction, resource optimization, and improved project management. This is a highly beneficial application, especially for developing countries where resource scarcity is a major problem.
2. Promotion of sustainable practices: Construction projects may more closely follow sustainable practices by incorporating RFID technology. With the use of technology, sustainable activities may be tracked and recorded, and reliable data can be obtained to guarantee adherence to environmental regulations. This may result in lower greenhouse gas emissions, more energy efficiency, and a lessening of the negative effects of building on the environment.
3. Cost savings and economic benefits: RFID technology implementation may save costs by reducing waste and increasing efficiency. Due to the technology's capacity to improve productivity and streamline procedures, projects may be finished more quickly and with fewer resources. This economic advantage is especially significant for developing countries, where budgetary restrictions sometimes restrict the breadth and size of building initiatives.
4. Support for policy and decision-making: The results of the study may be used to educate stakeholders and policymakers in the construction sector about the advantages of RFID technology. The research can aid in the formulation of laws and other initiatives that promote the use of RFID technology by showcasing the useful benefits of these instruments. This might result in greater adoption of RFID in building projects, therefore advancing the sector's efficiency and sustainability.
5. Training and capacity building: Sufficient training and capacity building are necessary for the effective application of RFID technology. The study emphasizes how important it is to have education and training programs in place to ensure that construction workers have the know-how to utilize RFID tools efficiently. This has important practical implications, particularly for developing countries where adopting new technology may be hampered by a lack of technical know-how.

## 6. Conclusion

This study examined the RFID tools in building projects and how they assist in developing the country's construction industry. Some countries have experienced faster growth as a result of the deployment of RFID in the building industry. Based on the survey results, using EFA, the RFID tools were classified under two constructs. The prioritization of these tools was studied using SEM-ANN. The study's findings can ensure the successful implementation of RFID tools in the construction industry of developing countries. By adopting and integrating RFID technologies, organizations can focus on project objectives related to time, cost, and efficiency. This, in turn, can lead to higher success rates in construction projects. The current results provide valuable insights for owners, consultants, and constructors, helping them assess and choose appropriate RFID tools to enhance planning, consistency, and efficiency in construction projects.

This study provides practical guidance for government and industry stakeholders and contributes to the broader adoption of RFID technology in construction as follows:

- Adoption of RFID technology: Construction companies should consider adopting RFID technology to enhance project tracking, inventory management, and resource allocation.
- Training and development: Organizations should invest in training programs to ensure that personnel are proficient in using RFID tools.

- Policy integration: Governments and industry bodies should develop policies that encourage the integration of RFID technology in construction practices.
- Future research: Further studies should explore the long-term impacts of RFID technology on various aspects of construction, including sustainability and worker safety.

## Ethical approval

The authors would like to clarify that the respondents participated in the study by consenting to contribute and completing the questionnaire. No recordings were made during the consent process. The authors ensured the confidentiality of the responses and did not share any personal information of the respondents. The data collected was solely used for the analysis presented in the study.

## Authors' contributions

Ahmed Farouk Kineber, Ayodeji Emmanuel Oke, Nehal Elshaboury, Mohamed Elseknidy, Mohammad Alhusban, Ahmad Zamil, and Ayman Altuwaim contributed to the study conception and design, data collection, analysis and interpretation of results, and manuscript. All authors read and approved the final manuscript.

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No potential conflict of interest was reported by the author(s).

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## Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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