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Development of a prototype system integration model for RFID technology with the internet of things and its implementation to improve precast concrete material management in Indonesia

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A B S T R A C T

The adoption of technology in Indonesian construction is still developing at a slower pace than in other sectors, particularly in materials management. Among the automation technologies that can be developed for precast material management, is integrated RFID technology with the Internet of Things (IoT). This study therefore aims to analyze the correlation between factors influencing the implementation of integrated RFID technology with IoT for precast material management in Indonesia and to examine the development model of the integrated RFID technology system with IoT. The research methods include a questionnaire survey with PLS-SEM and the development of technology systems validated by experts. The results demonstrate that factors, such as resource availability, implementation cost, stakeholder involvement, implementation risk, and project conditions have a significant direct and indirect impact on the implementation of integrated RFID technology with IoT for precast material management. Among these factors, the implementation of risk factors has the most significant influence. Furthermore, the development of the integrated RFID technology system with IoT has proven to be beneficial, especially as an automation technology for data recording and visibility in precast material management.

1. Introduction

In Indonesia, construction issues represent a significant factor affecting the progress of construction projects, which can lead to project delays (Rita et al., 2022). The impacts resulting from construction issues include cost overruns compared to what was planned, additional time needed to complete the project, re-planning of all management aspects (schedule, costs, and resources), reputation damage to the company, a reduction in the productivity and efficiency of labor in completing the project (Azlan et al., 2012). One of the most significant challenges in construction projects is the management of resources, particularly materials (Aziz & Abdel-Hakam, 2016). Materials account for approximately 40-60% of project costs, making them a pivotal factor in project success (Intan et al., 2005). Material management challenges, including material shortages and substandard materials are among the factors contributing to project delays in Indonesia (Rita et al., 2022).

In the context of construction projects, materials are categorized into two distinct types: cast in situ and precast materials (Arnold et al., 2008). The precast industry in Indonesia is undergoing a period of development with the objective of supporting construction activities within the country. According to (Kementerian PUPR, 2017) “The Ministry of Public Works and Housing (PUPR) continues to promote the use of precast concrete technology, which is characterized by the advantages of standardized quality and safety, ensuring faster and more continuous concrete production processes”. The Directorate General of Construction has revealed that in 2014, the precast concrete industry accounted for approximately 16.61% of all concrete work undertaken in the nation. It is anticipated that this proportion will continue to be expanded until it reaches 30% of the total by 2019 (Alim, 2017). Furthermore, it is evident that demand for precast construction materials to facilitate infrastructure development has been on the rise on a global scale. The Indonesian Precast and Prestressed Company Association (AP3I) has indicated that the Netherlands has set a target demand rate of 60% for precast

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in 2019, while Finland has set a target of 90% for the same year (Syafii, 2017). In Indonesia, the precast material management system in construction projects has not yet implemented automation technology (RFID Technology) to support a more effective and efficient precast material management system. This happens in one of the toll road projects in DKI Jakarta, in 2022, there was an error in the installation of precast concrete structures, which were not placed correctly due to marking/data errors in material usage (Arganiz & Muslim, 2023). Regarding the tracking function, the issue arises due to the manual checking of precast materials, which leads to errors in data collection regarding the quantity and specifications of precast materials when there is a high volume of production (Patil & Shelake, 2021). The slow adoption of modern technology is frequently identified as a contributing factor. The Indonesian government has established the Making Indonesia 4.0 initiative as an integrative roadmap to implement a number of strategies designed to propel Indonesia into the top 10 global economies by 2030 (Ahad, 2022). The fourth industrial revolution has significant implications for the construction industry, particularly with regard to the utilization of technology-driven Building Information Modelling (BIM) and Internet of Things (IoT). National contractors are currently required to utilize BIM and IoT-based technology in the planning, execution, and operational processes for each project (Dinas PUPR, 2020).

BIM and IoT technologies are currently in a developmental phase. The Internet of Things (IoT), a term used for technologies that connect and integrate daily objects to the internet, employs microcontrollers, radios, and protocol stacks (Benhamaid et al., 2022). According to the National Cyber and Crypto Agency, the development of IoT usage for daily life is predicted to reach 31 billion devices in 2021 (Ayu, 2020). The adoption of IoT in Indonesia, particularly in the construction sector, has not kept pace with other countries. In 2016, the Future Investment Conference was held in Japan with the purpose of discussing smart construction (Wimala & Imanuela, 2022). One of the ideas behind digital transformation in the construction industry that makes use of the Internet of Things is smart construction. A 126% boost in productivity and a 20% decrease in fuel-related emissions were linked to the use of ICT in Japan's construction industry when compared to traditional methods. (Tateyama, 2017). Over the past two decades in India, real-time information systems have become an integral part of construction industry storage management (Patil & Shelake, 2021). There are various modern tracking technologies facilitating real-time material tracking and identification in a short period. One of the most widespread and promising non-contact wireless systems is Radio Frequency Identification (RFID) (Patil & Shelake, 2021). RFID in Indonesia is commonly utilized not in the construction phase but in the post-construction phase. In 2019, a state-owned toll road management company implemented RFID technology at 200 toll gates in Indonesia (Alexander, 2019). This technology allows vehicles to pass through toll gates without stopping because payments are directly identified through RFID technology. In addition to the beneficial impact on toll road payment systems, the implementation of RFID has a positive effect on construction material management (Ma et al., 2019). This is demonstrated by the ongoing Public Housing Project located in Tuen Mun District, New Territories, Hong Kong, where paperwork in the production and logistics stages has been reduced by 48.3% and 40%, respectively. This has led to an increase in production efficiency, with assembly times being reduced by 6.67% (Zhong et al., 2017). Significant savings in labor costs are associated with the time required to locate different components at the construction site (Zhong et al., 2017). The utilization of RFID in construction material management has the potential to enhance the precision of material planning, which may consequently yield substantial savings in costs and a notable improvement in the overall quality of construction (Wu & Liu, 2020). Furthermore, tracking the history of precast material usage from storage locations through the deployment of RFID technology can provide comprehensive data on the precast materials utilized, encompassing information such as usage details, specifications and the manufacturing plant of origin for the precast materials (Patil & Shelake, 2021).

Therefore, this research is deemed important to investigate because it can identify factors influencing the development of RFID technology integrated with IoT, thus enabling the development of an integrated RFID technology system model with IoT for precast material management in Indonesia. The system development is used to analyze the impact of implementing RFID technology integrated with IoT systems in the delivery and on-site construction phases of precast materials in construction projects in Indonesia.

2. Methodology

2.1. Research Flow

To get information about an activity and reach a specified goal, researchers use a methodical strategy known as the research method. An abstract model representing the research process is the research thinking framework. The following is the presentation in Fig. 1.

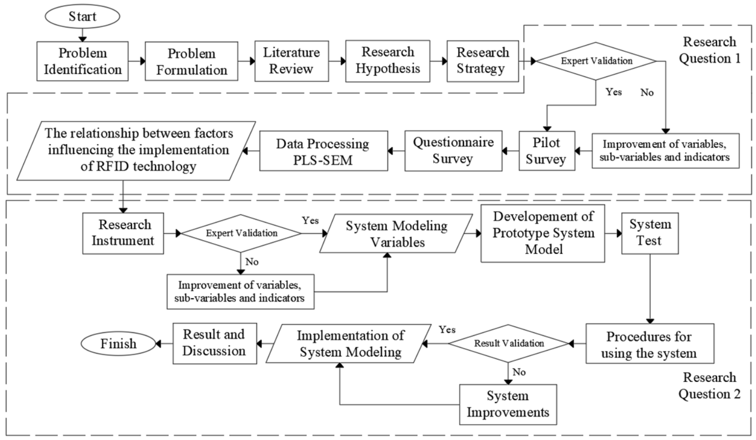

Fig. 1. Research Flow Framework

2.2. Research Design

Answers to the original research questions were confirmed by professionals with over a decade of expertise in precast material management and the application of innovative technologies in construction projects using survey data. Direct distribution of surveys in both online and in-person settings was a part of the validation procedure. Except for a few suggestions for improvements, most of the indicators were deemed suitable for data collection after receiving approval from the experts. The next step was to test how easy it was to understand the signs using a pilot survey. Ten people participated in the pilot survey, and the results showed that all the indications were clear enough to use in the full survey. Fifty people filled out the survey for this study topic, which used a Likert scale from 1 to 5. All the responders were up to date on the latest technical developments, particularly as it pertained to the automation tools used in construction, and they had worked with precast materials for at least two years. The survey questionnaire made use of the following study variables:

Table 1
Factors influencing the implementation of RFID technology integrated with IoT for precast material management

Code	Sub Variable	Code	Indicator	References
X.1.1	Resource Availability	X.1.1.1	Difficulty in searching for system components	(Ma et al., 2019), (Gustian et al., 2022)
		X.1.1.2	Limited knowledge of workers related to this technology	(Waqar et al., 2023), (Khin & Kee, 2022), (Arshad & Zayed, 2022)
		X.1.1.3	Lack of workers' ability to use and develop technology systems	(Waqar et al., 2023), (Khin & Kee, 2022), (Arshad & Zayed, 2022)
		X.1.1.4	Insufficient human resource training	(Waqar et al., 2023), (Arshad & Zayed, 2022), (Gustian et al., 2022)
		X.1.1.5	Increase in human resource needs in system development design	(Dardouri et al., 2022), (Waqar et al., 2023)
X.1.2	Implementation Costs	X.1.2.1	Additional System Development Component Costs	(Seyis & Sönmez, 2022), (Yan et al., 2018), (Waqar et al., 2023)
		X.1.2.2	Increased System Maintenance Costs	(Waqar et al., 2023), (Gustian et al., 2022), (Seyis & Sönmez, 2022)
		X.1.2.3	Increased Costs of System Development Experts	(Teizer et al., 2020), (Waqar et al., 2023), (Gustian et al., 2022)
X.1.3	Implementation Risks	X.1.3.1	System Development Errors	(Seyis & Sönmez, 2022), (Teizer et al., 2020)
		X.1.3.2	System Component Damage	(Seyis & Sönmez, 2022), (Zhou et al., 2021)
		X.1.3.3	Loss of System Components	(Zhou et al., 2021), (Teizer et al., 2020)
		X.1.3.4	Worker System Operation Errors	(Seyis & Sönmez, 2022), (Zhong et al., 2017), (Waqar et al., 2023)
		X.1.3.5	System Breach	(Seyis & Sönmez, 2022), (Zhong et al., 2017), (Waqar et al., 2023)
		X.1.3.6	System Development Time Requirements	(Teizer et al., 2020), (Patrucco et al., 2020), (Waqar et al., 2023)
X.1.4	Stakeholder Involvement	X.1.4.1	Technological Differences between Factory and Project Parties	(Waqar et al., 2023), (Gustian et al., 2022), (Arshad & Zayed, 2022)
		X.1.4.2	Involvement of Relatively Many Stakeholders	(Waqar et al., 2023), (Gustian et al., 2022), (Arshad & Zayed, 2022)
		X.1.4.3	Miscommunication among Stakeholders	(Arshad & Zayed, 2022), (Patrucco et al., 2020), (Aziz & Abdel-Hakam, 2016)
		X.1.4.4	Need for Information Access among Stakeholders	(Arshad & Zayed, 2022), (Ma et al., 2019), (Dardouri et al., 2022)
X.1.5	Project Conditions	X.1.5.1	Projects with a relatively large variety of precast materials	(Arshad & Zayed, 2022), (Ma et al., 2019), (Gustian et al., 2022)
		X.1.5.2	Extensive material storage space	(Arganiz & Muslim, 2023), (Abbott & Chua, 2020), (Arshad & Zayed, 2022), (Dardouri et al., 2022)
		X.1.5.3	Delayed project progress	(Arshad & Zayed, 2022), (Ma et al., 2019), (Teizer et al., 2020)
		X.1.5.4	Material recording errors frequently occur	(Aziz & Abdel-Hakam, 2016), (Arganiz & Muslim, 2023)
Y.1.1	Implementation of RFID Technology for precast materials	Y.1.1.1	RFID technology integrated with IoT is beneficial for precast materials	(Arshad & Zayed, 2022), (Ma et al., 2019), (Dardouri et al., 2022), (Teizer et al., 2020), (Patil & Shelake, 2021)
		Y.1.1.2	The development of an integrated RFID technology system with IoT can be simplified for construction projects in Indonesia	
		Y.1.1.3	Implementing an integrated RFID technology system with IoT can be a solution/alternative to improve precast material management in Indonesia	

The next research question aims to develop a prototype model of an integrated RFID technology system with IoT to enhance precast material management in Indonesia. Model development served as a strategy to address the influencing factors, especially those significantly impacting precast materials. For this research question, a system modeling method supported by coding process and expert validation. Expert validation was conducted to validate the indicators used in system modeling and the results obtained from system modeling. Concurrently, the coding process is executed with the objective of establishing a seamless integration between the system components. The following are the variables used for system modeling:

Table 2
Modeling Variables of an RFID technology system integrated with IoT to improve precast material management

Code	Sub Variable	Code	Indicator	References
X.2.1	Material Information Needs	X.2.1.1	Material Delivery Identity	(Dardouri et al., 2022), (Abbott & Chua, 2020), (Ma et al., 2019), (Zhong et al., 2017), (Teizer et al., 2020), (Patrucco et al., 2020), (Zhou et al., 2021), (Patil & Shelake, 2021)
		X.2.1.2	Precast Material Arrival Time	
		X.2.1.3	Precast Material Usage Time	
		X.2.1.4	Quantity of Precast Materials	
		X.2.1.5	Precast Material Specifications	
		X.2.1.6	Types of Precast Material Usage	
		X.2.1.7	Precast Material Construction Location	
		X.2.1.8	Precast Material Costs	

2.3. Data Processing Methods

SMARTPLS was employed as the software that would assist in processing the questionnaire data. The PLS-SEM methodology was employed to ascertain the correlation between independent variables and dependent variables, whereby the former exerts an influence on the latter. Additionally, correlation testing between the independent variables was conducted to obtain an optimal model. Three models—the outer, inner, and model fit—were tested with the data. We tested the outer model for reliability, discriminant validity, and convergent validity. We checked for convergent validity by looking at the AVE and loading factor data. (Hair et al., 2014). Additionally, discriminant validity was conducted to ensure that there are clear differences among variables, which was done through three methods: Fornell-Larcker, cross-loading, and HTMT (Hair et al., 2019). To determine how stable a questionnaire is when used as a variable indicator, reliability tests were performed. These tests involved assessing Cronbach's alpha values and composite reliability. Furthermore, the inner model testing consists of multicollinearity testing, hypothesis testing, and F-square. The purpose of multicollinearity testing is to demonstrate that there is no significant correlation among the independent variables (Hair et al., 2014). The inner VIF value below 5 indicates that there is no multicollinearity among independent variables. Hypothesis testing was performed by examining the t-statistic or p-value. A t-statistic value exceeding the t-table value of 1.96 indicates a significant effect of variables. Moreover, the F-square value was used to determine the significance of variables at the structural level, where values of 0.02 – 0.35 are considered moderate and > 0.35 are considered high. Finally, the model fit testing consists of R-square, "Q-square, Standardized Root Mean Square Residual (SRMR), and Goodness of Fit Index (GoF Index). R-Square depicts the magnitude of the influence of endogenous variables on their exogenous variables", where values of 0.33 – 0.66 are considered moderate and greater than 0.66, which are considered high. How well a study's observations predict changes in endogenous variables is indicated by Q-Square, which is an indicator of predictive accuracy. The model is predictively relevant if the Q-squared value is greater than 0. One way to find out how well a statistical model fits the data is to use the Standardized Root Mean Square Residual (SRMR) test. (Henseler & Sarstedt, 2013). The model is considered to have an acceptable fit if the SRMR value is between 0.08 - 0.10. The GoF index evaluates the overall model in terms of measurement and structural models, where a value greater than 0.36 is classified into the high GoF Index category.

System modelling was also conducted by creating a simple prototype to produce an integrated system to address significant impacting factors. The following is the flow of system modeling conducted:

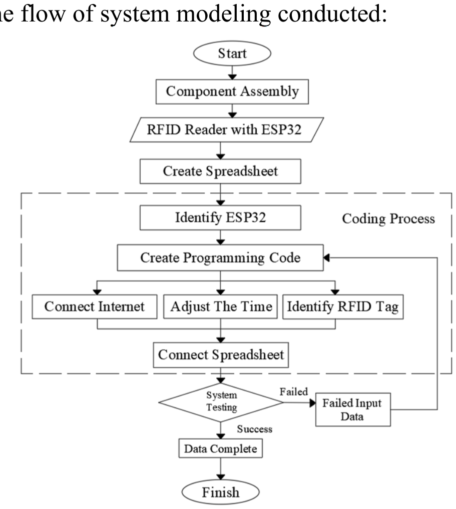

Fig. 2. System Modeling Flow

3. Results and Discussion

3.1. Factors influencing the implementation of RFID technology integrated with IoT for precast material management

The bulk of the 50 respondents (48%) were state-owned contractors, with 80% holding a bachelor's degree and 52% having two to nine years of work experience. Most responders (52%), geographically speaking, were located in DKI Jakarta. Here is a rundown of the profiles of the responders about this research question:

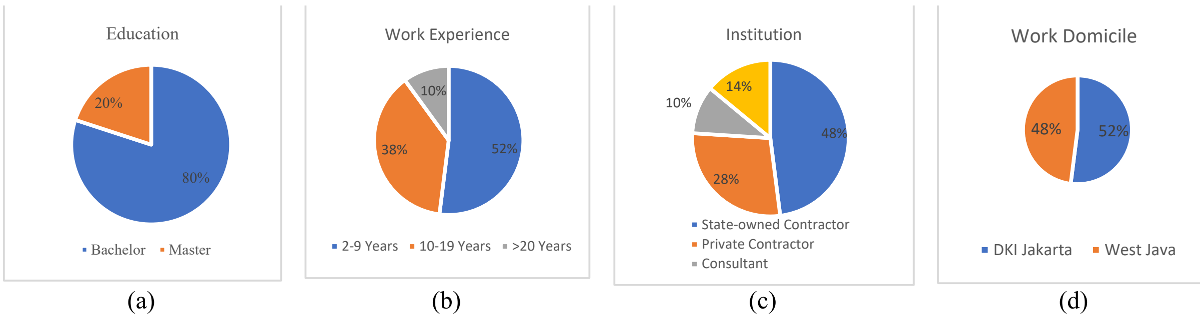

Fig. 3. (a) Respondent's Education, (b) Respondent's Work Experience, (c) Respondent's Institution, (d) Respondent's Work Domicile

This research examined the impact of RFID and the internet of things (IoT) on precast material management by collecting and analyzing data from each indication of these aspects. Data testing using PLS-SEM yielded the following results:

Table 3
Convergent Validity and Reliability Test Results

Indicator	Convergent Validity		Reliability Test	
	Loading Factor	AVE	Cronbach's alpha	Composite Reliability
X.1.1.1	0.773	0.705	0.937	0.905
X.1.1.2	0.837			
X.1.1.3	0.850			
X.1.1.4	0.847			
X.1.1.5	0.888			
X.1.2.1	0.913	0.770	0.901	0.857
X.1.2.2	0.914			
X.1.2.3	0.801			
X.1.3.1	0.889	0.762	0.895	0.943
X.1.3.2	0.901			
X.1.3.3	0.853			
X.1.3.4	0.838			
X.1.3.5	0.850			
X.1.3.6	0.902			
X.1.4.1	0.884	0.732	0.877	0.881
X.1.4.2	0.836			
X.1.4.3	0.817			
X.1.4.4	0.883			
X.1.5.1	0.885	0.771	0.849	0.919
X.1.5.2	0.828			
X.1.5.3	0.886			
X.1.5.4	0.910			
Y.1.1.1	0.857	0.715	0.801	0.818
Y.1.1.2	0.783			
Y.1.1.3	0.893			

Convergence validity testing was conducted on each sub-variable and indicator using loading factor values and AVE. All variables and indicators can be considered valid because the loading factor values exceed 0.7, and the average variance extracted value exceeds (AVE) 0.5. Additionally, reliability testing indicates that each research variable is consistent, thus yielding approximately the same results when the study is repeated, as they have Composite Reliability and Cronbach's Alpha values greater than 0.7. Discriminant validity testing was conducted using the Fornell Larcker, Cross Loading, and Heterotrait Monotrait Ratio (HTMT) methods. With the Fornell Larcker method, each variable has a distinct construct or does not have similar meanings to other variables because each variable has higher values for its latent variable compared to other variables. Indicators for the resource availability, implementation cost, implementation risk, stakeholder involvement, project conditions, and RFID technology application for precast material variables focus on measuring their respective latent variables and measuring lower than other variables. In the Cross Loading method, each indicator can be considered as representing its respective latent variable because each indicator towards its latent variable has values that are not significantly different. Meanwhile, the Heterotrait Monotrait Ratio (HTMT) method shows that all variables can be considered valid because the HTMT values for each variable are below 0.9 compared to other variables.

	X.1.2	X.1.4	X.1.1	X.1.5	Y.1.1	X.1.3
X.1.2	0.878					
X.1.4	0.672	0.855				
X.1.1	0.597	0.694	0.840			
X.1.5	0.627	0.602	0.463	0.878		
Y.1.1	0.729	0.444	0.633	0.591	0.846	
X.1.3	0.683	0.427	0.605	0.637	0.796	0.873

(a)

	X.1.2	X.1.4	X.1.1	X.1.5	Y.1.1	X.1.3
X.1.2						
X.1.4	0.781					
X.1.1	0.681	0.786				
X.1.5	0.708	0.664	0.496			
Y.1.1	0.870	0.529	0.739	0.689		
X.1.3	0.754	0.459	0.649	0.679	0.899	

(b)

	X.1.2	X.1.4	X.1.1	X.1.5	Y.1.1	X.1.3
X.1.1.1	0.480	0.636	0.773	0.355	0.412	0.426
X.1.1.2	0.519	0.564	0.837	0.418	0.552	0.547
X.1.1.3	0.380	0.525	0.850	0.441	0.514	0.564
X.1.1.4	0.484	0.570	0.847	0.296	0.503	0.430
X.1.1.5	0.631	0.634	0.888	0.416	0.642	0.549
X.1.2.1	0.913	0.647	0.557	0.584	0.646	0.594
X.1.2.2	0.914	0.557	0.549	0.520	0.688	0.638
X.1.2.3	0.801	0.568	0.463	0.552	0.579	0.563
X.1.3.1	0.604	0.313	0.465	0.533	0.647	0.889
X.1.3.2	0.690	0.485	0.566	0.638	0.778	0.901
X.1.3.3	0.502	0.312	0.513	0.547	0.615	0.853
X.1.3.4	0.443	0.173	0.413	0.461	0.586	0.838
X.1.3.5	0.549	0.410	0.565	0.603	0.675	0.850
X.1.3.6	0.737	0.484	0.618	0.541	0.823	0.902
X.1.4.1	0.618	0.884	0.629	0.538	0.394	0.401
X.1.4.2	0.619	0.836	0.501	0.578	0.350	0.369
X.1.4.3	0.511	0.817	0.582	0.465	0.354	0.341
X.1.4.4	0.549	0.883	0.658	0.479	0.418	0.348
X.1.5.1	0.607	0.640	0.432	0.885	0.551	0.568
X.1.5.2	0.440	0.397	0.243	0.828	0.394	0.422
X.1.5.3	0.473	0.429	0.398	0.886	0.505	0.558
X.1.5.4	0.647	0.606	0.504	0.910	0.593	0.652
Y.1.1.1	0.719	0.369	0.515	0.500	0.857	0.711
Y.1.1.2	0.477	0.360	0.506	0.513	0.783	0.538
Y.1.1.3	0.628	0.399	0.584	0.496	0.893	0.748

(c)

Fig. 4. (a) Fornell Larcker, (b) Cross Loading, (c) HTMT

Table 4
Hypothesis Testing Results

Direct Effect			Indirect Effect		
Indicator	T statistics	P values	Indicator	T statistics	P values
X.1.3 → Y.1.1	3.026	0.002	X.1.5 → X.1.3 → Y.1.1	2.343	0.019
X.1.1 → Y.1.1	2.646	0.008	X.1.4 → X.1.3 → Y.1.1	2.209	0.027
X.1.2 → Y.1.1	2.118	0.034	X.1.1 → X.1.3 → Y.1.1	2.057	0.040
X.1.4 → Y.1.1	1.811	0.070	X.1.2 → X.1.3 → Y.1.1	2.042	0.041
X.1.5 → Y.1.1	0.806	0.421			
X.1.2 → X.1.3	3.310	0.001			
X.1.5 → X.1.3	3.275	0.001			
X.1.1 → X.1.3	2.943	0.003			
X.1.4 → X.1.3	2.810	0.005			

In order to manage precast materials, the results of hypothesis testing show that the variables of resource availability, implementation cost, and implementation risk significantly impact the implementation of RFID technology integrated with the internet of things. Nevertheless, with T-Statistics values below 1.96 and P-Values over 0.05, the project circumstances and stakeholder participation variables do not significantly impact the application of RFID technology combined with IoT for precast material management. Nevertheless, the variables of resource availability, implementation cost, stakeholder involvement, and project conditions continue to exert a significant indirect influence on the implementation of RFID technology integrated with IoT for precast material management.

Table 5
Multicollinear and F-Square Test Results

	Multicollinear Test		F-Square Test	
	Y.1.1	X.1.3	Y.1.1	X.1.3
X.1.1	2.630	2.054	0.115	0.281
X.1.2	2.831	2.248	0.196	0.259
X.1.3	2.886	-	0.198	-
X.1.4	3.150	2.615	0.075	0.205
X.1.5	2.308	1.828	0.023	0.263

The multicollinearity test indicates that there is no evidence of multicollinearity among the independent variables, as the Variance Inflation Factor (VIF) values for each variable are below five. This can be concluded that each independent variable is not related or similar to each other, thus there is no significant linear correlation among them, which makes it easier to distinguish the influence of each independent variable on its dependent variable. Additionally, the F-square test indicates the implementation cost, resource availability, and implementation risk variables exhibit a moderate level of significance on the implementation of RFID technology integrated with IoT for precast material management, while the stakeholder involvement and project conditions variables exhibit a low level of significance on this same implementation. Moreover, the level of significance between the implementation cost, stakeholder involvement, resource availability, and project conditions variables on implementation risk was found to be moderate, with the variable of resource availability approaching a high level of significance.

Furthermore, model fit testing is conducted by testing R-Square, Q-Square, SRMR, and GoF Index. The results of the R-Square test indicate that the influence of resource availability, implementation cost, stakeholder involvement, and project conditions overall has a high influence on implementation risk and the application of RFID technology for precast material management. The factors influencing the implementation of RFID technology integrated with IoT for precast material management have been depicted through the PLS-SEM model by 73.2%. Additionally, the factors related to implementation risk are also depicted by 65.3%, which can still be developed to achieve a better model. The Q-Square test results indicate a value of 0.582 for the application of RFID technology integrated with the Internet of Things (IoT) for precast material management and a value of 0.566 for implementation risk. A Q-Square value that exceeds 0 indicates that the PLS-SEM model accurately predicts or replicates the correlation between the observed variables. Moreover, the SRMR result with a value of 0.088 indicates that this research model fits the empirical data obtained, allowing the empirical data to explain the correlation between variables in the model. Lastly, the GoF Index test results indicate that the overall structural model of this study has a good fit between the data and the model, with a GoF index value of 0.717.

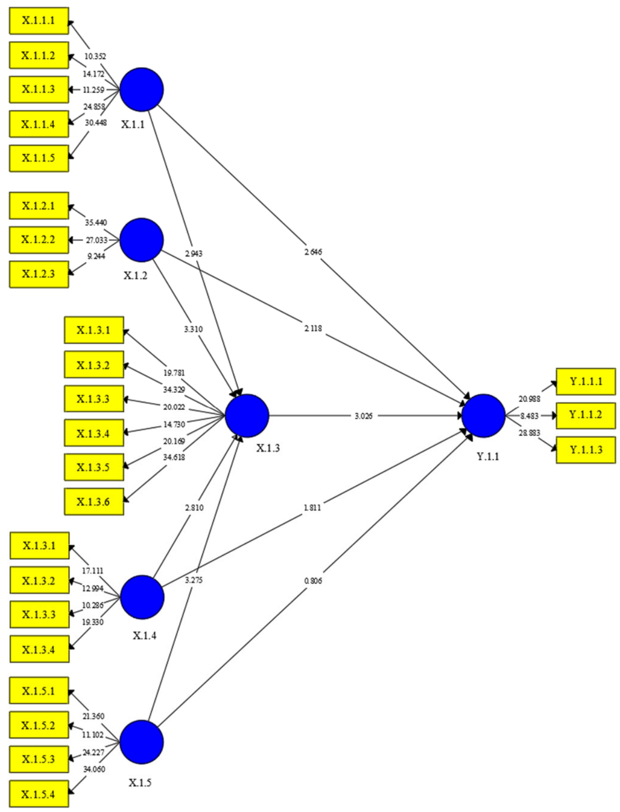

Fig. 5. Correlation Model between Influence Factors

The results of the PLS-SEM correlation model indicate which factors exert a significant influence on the implementation of RFID technology integrated with IoT for precast material management and how the indirect effects of correlation between variables affect the implementation of RFID technology integrated with IoT for precast material management.

Implementation risk has the highest level of significance on the implementation of RFID technology integrated with IoT for precast material management. The need for system development time and component damage are key indicators with the highest level of significance. In accordance with the findings of (Teizer et al., 2020), the lifespan of a component can result in component damage, thus leading to increased costs and time. Any malfunctions of the software or failures of the sensors can impede the acquisition, transmission and exchange of continuous and real-time data. (Seyis & Sönmez, 2022). Additionally, this technology also requires time for development, thereby prolonging the project planning phase. According to (Zhou et al., 2021), field workers frequently encounter difficulties in accurately scanning RFID tags, with instances of data loss due to damaged tags or loss of information. Therefore, the skills and knowledge of workers are also required in using this technology. This indicates that implementation risk also significantly mediates the influence of resource availability, implementation cost, stakeholder involvement, and project conditions on the implementation of RFID technology integrated with IoT for precast material management.

The second-highest level of significance on the implementation of RFID technology integrated with IoT for precast material management is the availability of resources. According to (Seyis & Sönmez, 2022), one of the key barriers to the adoption of RFID technology in construction is the lack of trained personnel who can effectively utilize the technology. The necessity for human resources is paramount, as this technology does not entirely supplant human functions, in contrast to robotic technology. The heterogeneity of skills and knowledge among workers necessitates training in the development and utilization of this system (Waqar et al., 2023). According to (Kementerian PUPR Republik Indonesia, 2021), the challenges encountered by the construction industry in Indonesia in implementing digital transformation can be attributed to two primary factors: the dearth of adequately trained personnel and the reluctance of construction professionals to develop new skills. According to (Teizer et al., 2020), many factors need to be considered in developing this system, such as the battery life of components, network loss during data transmission, and the use of gateways/readers, which could pose risks if not monitored.

The implementation cost is the third-highest level of significance on the implementation of RFID technology integrated with IoT for precast material management. According to (Waqar et al., 2023), financial barriers are one of the determining factors, namely the implementation costs from design to maintenance, which are quite high. The requirement for components in RFID technology systems is considerable, leading to additional costs. The need for RFID tags is also adjusted according to the amount of material because RFID tags will be installed on each material as an identity form for each material (Dardouri et al., 2022). Other component requirements, such as RFID readers are also adjusted according to material phases, including production, logistics, and on-site construction (Zhou et al., 2021).

Stakeholder involvement does not have a significant direct impact on the implementation of RFID technology integrated with IoT for precast material management. However, stakeholder involvement still has a significant indirect influence on the implementation of RFID technology integrated with IoT for precast material management. According to (Seyis & Sönmez, 2022), the challenge of ensuring the involvement of various stakeholders in the acquisition of information is the least influential factor, yet it still has a notable impact. This is because new innovations in the form of technology have a broad influence on project execution. Therefore, the more significant factors are those that are more general to project conditions such as implementation risk, implementation cost, and resource availability. The transparency of material information accessible to involved stakeholders can prevent miscommunication and increase stakeholder trust. This is supported by (Zhou et al., 2021), who state that one of the primary obstacles to effective management of construction materials is the dearth of automated decision-support and information-sharing systems. This indicates the need for other stakeholders to access the required material information. In addition, project conditions also do not have a significant direct impact on the implementation of RFID technology integrated with IoT for precast material management. However, the conditions of the project continue to exert a considerable indirect influence on the implementation of RFID technology integrated with IoT for precast material management through implementation risk. The influence of project conditions is the least significant factor among all other factors. Material data errors are the main indicator with the highest level of significance. There are also changes in the type and specifications of materials during construction, material damage at storage locations, and poor material handling on-site necessitate automated material data collection in construction projects (Aziz & Abdel-Hakam, 2016). Additionally, manually collected data tends to be incomplete and inaccurate, which renders it ineffective in providing timely and accurate support for decision-making processes. (Zhou et al., 2021).

3.2. Prototype model of an RFID-integrated IoT system for precast material management in Indonesia

The modeling process begins with assembling components and creating a spreadsheet template according to the indicators of variable X.2. This aims to determine the information that RFID will be able to identify later on. The spreadsheet will serve as the entry point for information from the RFID reader. Next, the coding process was carried out to connect the RFID system with related systems. Firstly, coding was done by identifying the internet source that will be used in this system, which is WiFi. Writing computer code for WiFi is used to help connect the RFID reader to the internet system. Subsequently, a coding process was done to obtain real-time from an NTP server by identifying the time according to its region so that when the system is used, it is expected that the time will match between real-time and data recording time. Next, coding was also conducted to identify RFID tags. This programming is aimed at enabling components to read the identification tags to be used and can be sent to a platform, which in this study is a spreadsheet acting as a cloud system. Finally, coding was used to send data to the spreadsheet. All data on the RFID tag would be sent to the spreadsheet when reading the tag. The check performed was whether all data has been entered; if not, it means that there is still data that has not been identified by the coding system. Fig. 6 presents the correlation scheme of the modeling results. The system components utilized simple components consisting of cards on RFID Tags and RFID Readers with a frequency of 13.56 MHz. Additionally, the ESP32 component used is an integrated component that can be programmed with the Arduino IDE software. The requirement for these components is that the RFID Tag has the same radio frequency as the RFID Reader. This aims to ensure that the RFID Tag could be read by the RFID Reader due to having the same specifications (Goodrum et al., 2006). These components are easily accessible online and do not have high specifications. With relatively low frequency specifications in the system components, it indicates that the component costs are relatively low according to experts' opinions. In this system, two RFID Tags were allocated as the identities of one column and one beam, respectively. Additionally, two RFID Readers and ESP32 were used according to the two phases accommodated by this system, namely the material delivery phase and on-site construction. Moreover, the RFID Tag and RFID Reader have the following specifications: Environmental Operating Temperature ranges from -20 to 80 degrees Celsius and Environmental Storage Temperature ranges from -40 to 85 degrees Celsius. This could prevent sudden and rapid component damage. Based on the specifications, these components could be used according to the environmental temperature at the project site and storage space.

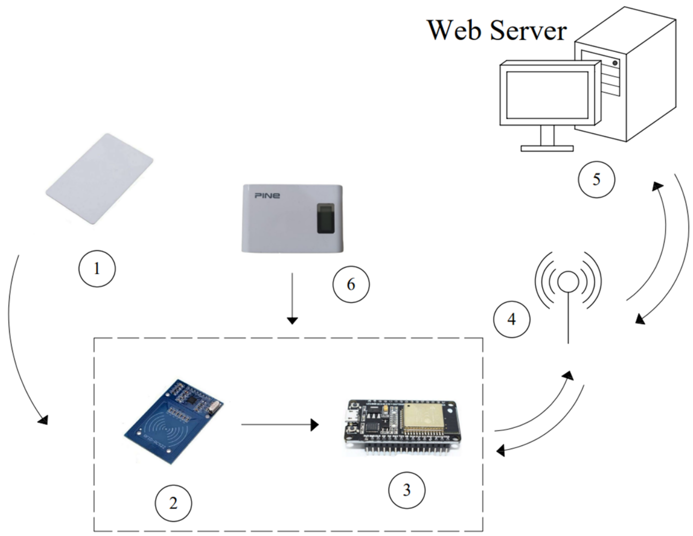

Fig. 6. System Modeling Results Correlation Scheme

Table 6
System Component Explanation

No	Component	Information
1	RFID Tag	• As an identity for precast materials containing various information • The requirement for the RFID Tag used is one RFID Tag for one precast material.
2	RFID Reader	• Reading information on the RFID Tag • Sending RFID data to ESP32 • Held by every person performing data collection • Each precast material process has one RFID Reader
3	ESP32	• Receiving input from RFID Reader • Sending data to the web server • Installed as a single unit with the RFID Reader • Receiving programming code from the Web Server
4	Internet connection	• Serves to connect ESP32 and RFID Reader to the Web Server • Internet connection uses WiFi
5	Web Server	• The Web Server used is a cloud system (data storage) • Receiving all RFID tag data from ESP32. • Storing RFID tag data in the database
6	Power Bank	• Supplying electric power to the RFID Reader and ESP32 components

The RFID Tag was used as the identity for the precast material, and the RFID Reader as a component to read the identity of the precast material. In this system, the IoT used is a data storage system in the form of an Excel Spreadsheet that can be accessed online. Microsoft Excel is one of the software commonly used in projects to monitor project progress, so the data received from the created system can be well-integrated with all project progress data. Additionally, this system is intended for projects with a relatively large variety of precast concrete materials because it poses a risk of data entry errors (Aziz & Abdel-Hakam, 2016). There are no specific types of precast concrete materials that can be used by this system because the more types of precast concrete materials available, the more beneficial the system will be for automatic data entry according to experts. The system modeling results and system usage flow have been validated by three experts with experience in the management of precast materials and the use of new technologies in construction projects. Below are the profiles of the experts used:

Table 7
Expert Profile

Expert	Education	Institution	Position	Work Experience
P1	Master	Owner	TollRoad Maintainance Finance Director	35 Years
P2	Master	State-Owned Contractor	Director of Civil and Trackwork	22 Years
P3	Master	Private Contractor	Project Manager	10 Years

All three experts have validated the system usage flow for the precast material phase. The system usage is divided into two main phases: the precast material delivery phase and the on-site precast material construction phase. Below are the results of the system usage flow for the precast material delivery phase and the on-site precast material construction phase:

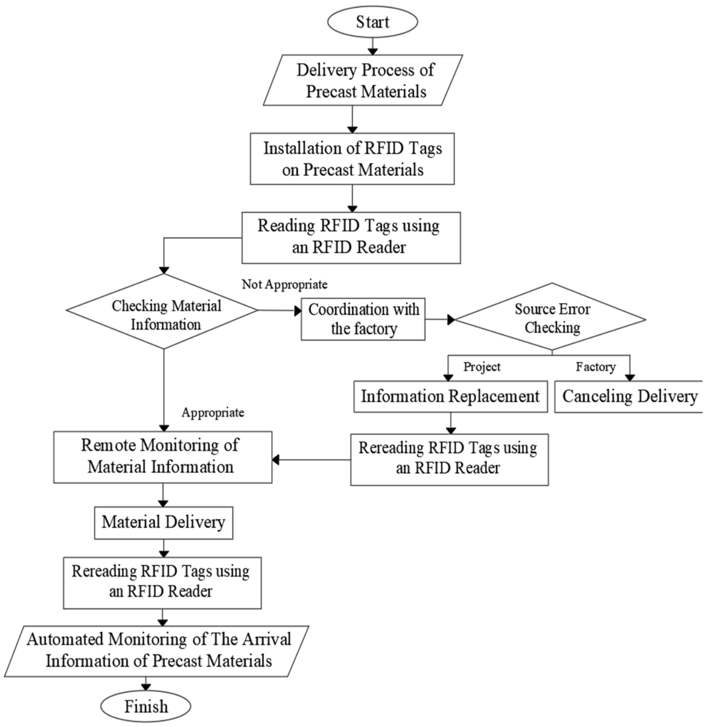

Fig. 7. System Usage Flow

In the material delivery process, the system usage flow begins with the installation of RFID tags on precast materials. The installation of RFID tags was carried out at the factory while the project's PIC was conducting a final check on the precast materials to be shipped. The RFID tags were read by placing or bringing the RFID reader, which was already connected to the ESP32 and power supply components, close to the RFID tags installed on each precast material. After the reading process is done, a check process was conducted to compare the information provided by the factory, including documents and actual conditions in the field, with the project's requirements as indicated by the reading results. If there are discrepancies between the factory's data and the project's requirements, the coordination between the project and the factory could be initiated. Project managers or owners can monitor the real-time differences in information using RFID tags reading listed in the precast material delivery monitoring spreadsheet. This allows for quick and efficient decision-making regardless of the circumstances because both the project team and the factory have direct access to incoming data. The source of errors could be identified to determine whether they originate from the factory or the project team. If the error is from the factory, the delivery must be canceled, and losses or other decisions can be made after an appropriate solution is found, although this technology does not accommodate functions up to this extent. If the error lies with the project team, information exchange was rectified by modifying information in the Arduino IDE software. When the re-reading process was conducted, the obtained information is already correct as it is integrated with IoT or the existing spreadsheet. This process aims to ensure that the corrected information is recorded and logged, thus showing a history of information changes. This re-reading was performed to record the delivery time from the factory location. Accurate information can be monitored by the project team. When the material arrives at the project site, RFID tag readings are also performed again on each material to record the time until the material reaches each project.

Fig. 8. Illustration of the Implementation of RFID Technology

In the on-site construction process, the system usage flow was started with checking the condition of RFID tags. This check was done by verifying whether the RFID tags installed on the precast materials are still intact or not. After that, the RFID tags were also checked to see if they are still functional/not damaged by reading them and checking if the information entered the data spreadsheet. If the RFID tag was in a good condition, the location of the material installation could be checked by reading the RFID tag to ensure that the material has been installed in the correct location. If the RFID tag was damaged/lost, the replacement was needed to symbolize a new identity for the precast material. Each RFID tag has a unique code. This is able to support traceability, indicating that the RFID tag on the respective material has been replaced due to loss/damage, so there will be no miscommunication or doubt, as the traceability evidence could be seen. When RFID tags are damaged/lost, they simply require replacement with new ones. Subsequently, the RFID code needs to be re-identified in the Arduino IDE software to ensure that the RFID tag can have the same information as the previous one. After replacement, the RFID tag in good condition was tested again to read the RFID tag to determine if the information could enter the data spreadsheet. Next, RFID tag readings were conducted to match the material installation location with the intended material. If the material type and its installation location did not match, the project team immediately saw this in real-time as the data was directly entered into the spreadsheet. Even when not on-site, project personnel still are informed and review the errors. Afterward, a re-reading was performed once the material matches its installation location. This reading also aids in monitoring project progress based on the installation time of precast materials. This system is user-friendly, reducing the risk of system misuse by workers. However, workers still need the skills to use the RFID reader to retrieve data stored on the RFID tags (Xue et al., 2018). The following are the benefits of the developed system:

RFID Code	Material Code	Material			Delivery Time		Arrival Time		Installation Time	
		Material Type	Specification	Location of Use	Planning	Realization	Planning	Realization	Planning	Realization
9061f420	K1A	Concrete Column	K350	A1		Monday,-November-27-2023 -14:01:55		Monday,-November-27-2023 -17:00:00		Tuesday,-November-28-2023 -16:04:29
a0b2720	B1A	Concrete Beam	K300	B1		Monday,-December-04-2023 -16:18:37		Monday,-December-04-2023 -18:05:03		Tuesday,-December-05-2023 -16:19:38

Material		Material Cost		Delivery Monitoring			
Material Type	Specification	Planning	Realization	Nov-23	Dec-23	Jan-24	Feb-24
Concrete Column	K350		Rp1.200.000,00	Rp1.200.000,00			
Concrete Beam	K300		Rp1.000.000,00		Rp1.000.000,00		

RFID Code	PIC	Material Code	Subcontractor/ Supplier	Letter Number
9061f420	Budi	K1A	PT. XYZ	1
a0b2720	Bimo	B1A	PT. ABC	2

RFID Code	PIC	Material Code	Subcontractor/ Supplier	Material			Material Quantity		Quantity Monitoing			
				Material Type	Specification	Location of Use	Planning	Realization	Nov-23	Dec-23	Jan-24	Feb-24
9061f420	Budi	K1A	PT.XYZ	Concrete Column	K350	A1		1	1			
a0b2720	Bimo	B1A	PT.ABC	Concrete Beam	K300	B1		1		1		

Fig. 9. Benefits of System Modeling

The modeling results of the RFID technology system integrated with IoT provide benefits for precast material management, especially for automatic data recording. The data entered into this system are dummy data. The use of RFID technology integrated with IoT technology offers the potential to provide a comprehensive understanding of the historical usage of precast materials (Patil & Shelake, 2021). The history of material usage can assist in monitoring the progress of material utilization in projects from arrival to installation. This data recording is highly useful as it is able to minimize errors in precast material usage on-site and aid in planning the procurement of other precast materials. This RFID technology system integrated with IoT can monitor the real-time schedule of delivery, arrival, and usage of materials, which is automatically recorded in the project data recording system (Zhou et al., 2021). This helps in observing the progress of precast material scheduling between planning and implementation. This data can also serve as supporting evidence in case of material delivery issues due to differences in delivery times. Moreover, it can be used as evidence if the project experiences delays due to significant differences in time between the completion of precast materials and their usage. This system has the ability to track sender information from the factory by storing material data information, including the necessary factory information (Wu & Liu, 2020). Automatic recording of sender information can help prevent disputes as this data can serve as evidence, and its traceability can be tracked if changes occur.

Tracking sender information in this system includes material codes, subcontractor/supplier names, delivery letter numbers, material types, and material specifications. Subcontractor/supplier names and delivery letter numbers are two crucial indications because experts believe that recording factory identities can help solve problems in case of precast material damage, holding relevant parties accountable. This system can also track the location of precast material construction before installation. According to (Arganiz & Muslim, 2023), a significant challenge in the management of precast materials in Indonesia is incorrect material installation due to the disappearance of markings on the material, resulting in incorrect installation compared to the plan. This leads to additional costs and time due to rework/dismantling. With automatic and real-time accessible information, project managers can grasp on-site conditions and make quicker decisions to avoid ongoing errors (Ma et al., 2019). Furthermore, the progress of precast material costs could be monitored based on monthly timelines. This aids in creating material S-Curves as cost data is automatically inputted. A comparison of material costs was created between actual and planned expenditures (Dardouri et al., 2022). It is also crucial to monitor the requisite quantity of precast material for the project. A diverse range of precast materials can potentially lead to errors in material data.

Additionally, manual precast material recording lacks integration with other systems and requires time to access and retrieve hardcopy data files. This system facilitates stakeholders' access to information by providing a direct link to the data spreadsheet, enhancing data security and privacy, and accessible only to involved parties (Seyis & Sönmez, 2022). Access to viewing and editing precast material information can be restricted, ensuring transparency for all stakeholders. They can monitor real-time information and progress of precast materials at the construction site, detecting transparently any changes in information to prevent fraud. In case of RFID Tag replacement in the system, the identification process was carried out by comparing the RFID Tag codes in the data spreadsheet. Moreover, information changes were recorded through change history in the data spreadsheet.

4. Conclusions

The following conclusions were drawn from this research on the development of a prototype model integrating RFID technology with the IoT to improve the management of precast concrete materials in Indonesia:

1. The availability of resources, implementation costs, and implementation risks exert a significant direct impact on the implementation of RFID technology integrated with IoT for precast material management. Meanwhile, stakeholder involvement and project conditions do not have a significant direct impact on the adoption of RFID technology integrated with IoT for precast material management. The implementation risk factor also significantly mediates the influence of resource availability, implementation costs, stakeholder involvement, and project conditions on the implementation of RFID technology integrated with IoT for precast material management.
2. Implementation risk has the highest level of significance in the implementation of RFID technology integrated with IoT for precast material management. The development time of the system and component damage are the primary factors with the highest level of significance
3. The developed system can be utilized during the precast material delivery process and on-site construction. The system application involves placing/proximity of the RFID reader to the RFID tag, enabling the required information to be automatically and in real-time stored in the data spreadsheet. Therefore, the development of a simple RFID technology system integrated with IoT could be beneficial and visible for implementation in precast material management, especially to support automatic data recording functions.
4. System modeling has become an appropriate strategy in the development of RFID technology integrated with IoT for precast materials, considering the factors influencing system development.

This research has several limitations that suggest further development opportunities. For instance, the prefabrication process was not included in this study's scope, and the IoT integrated with RFID technology is a web-based application for data storage. Further research could involve conducting case studies to test the system on construction projects to enhance system visibility. The development of RFID technology systems could integrate with BIM, Vision Systems, and other technologies. Additionally, RFID technology systems could be developed to encompass a broader scope of precast material management processes, particularly in prefabrication and storage processes.

Author Contributions

Conceptualization, P.A. and F.M.; methodology, P.A. and F.M.; software, P.A.; validation, P.A. and F.M.; "formal analysis, P.A. and F.M.; investigation, P.A. and F.M.; resources, P.A.; data curation, P.A.; writing—original draft preparation, P.A.; writing—review and editing, P.A. and F.M.; visualization, F.M.; supervision, F.M.; project administration, P.A. and F.M.; funding acquisition, P.A. and F.M. All authors have read and agreed to the published version of the manuscript".

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