BIM AND IOT INTEGRATION TO SUPPORT MANAGEMENT PROCESSES:

AN APPLICATION FOR PRECAST CONCRETE SYSTEMS

LIMA, Caio Mendes (1)
FERREIRA, Emerson A. M. (2)
CALMON, João Luiz (3)

(1) UNIVERSIDADE FEDERAL DA BAHIA
(2) UNIVERSIDADE FEDERAL DA BAHIA
(3) UNIVERSIDADE FEDERAL DO ESPÍRITO SANTO


(1)


(2)


(3)

Abstract: The precast concrete system has grown more and more in recent years. This growth is due to benefits such as agility in the construction process, cost reduction, and better quality. However, uncertainties and interdependencies during management processes are problems present in this constructive system. Given these challenges, this article proposes using technologies such as IoT, cloud computing, and RFID applied together with BIM to improve this situation. For the construction of this proposed system, it was necessary to identify user requirements, the development of a prototyping RFID reader, an application, a web platform, in addition to laboratory and field tests. Finally, the system contributed to the monitoring of quality inspection during the production, transport, and assembly stages, communication between sectors, and support in the assembly stage through the Digital twin.

Keywords: BIM; IoT; RFID; Precast Concrete Systems

1. INTRODUCTION

The prefabricated system still presents an advanced degree of uncertainties, which are often triggered by the lack of predictability of the processes, a large displacement between the factory and the construction site, lack of coordination between activities before construction, low reliability in the project assembly, among other factors (PEÑALOZA et al., 2016). Another challenge shared by this constructive system is the low efficiency and collaboration between the parties involved in the decision-making stage. This problem is due to different isolated management processes that do not communicate and hinder the desired information flow (LI et al., 2019).

In the search for alternatives that improve the current management context, the construction industry has witnessed a series of innovative solutions that make it possible to achieve more efficient management of executive construction projects (NARANJE; SWARNALATHA, 2019). In this sense, Dallasega, Rauch, and Linder (2018) conclude that these solutions have been achieved through a digital transformation and that the central technology used for this purpose was Building Information Modeling (BIM).

Also, Zhong et al. (2017) and Yin et al. (2019) explain that due to the gains in visual resources in the project, improvement in the exchange of information, higher productivity, and higher product quality, BIM has been applied more and more in prefabricated buildings.

Another technology detected was Radio Frequency Identification (RFID), which supports construction management and can be associated with the BIM platform. The construction industry has increasingly adopted RFID, as this technology has brought benefits related to automated tracking of physical resources (IKONEN et al., 2013). In addition, the authors Zhong et al. (2017) found that the use of BIM and RFID integrated with the Internet of Things (IoT) infrastructure has enabled gains in terms of connectivity and information sharing. Zhao et al. (2019) understand that the IoT will be inserted in the BIM models so that the real conditions found in the field are automatically reproduced in the projected model and that the RFID tags will work as unique identifiers for each prefabricated element.

Besides, the authors Coutinho, Carneiro, and Greve (2016) emphasize that Cloud Computing has brought complementary and essential aspects in the context of IoT, such as processing capacity, storage, data analysis, among others. Therefore, this technology has a great potential to support large-scale web services on the Internet, in addition to enabling the effective and optimized use of hardware and software resources in Information Technology ecosystems.

Although the integration of these technologies demonstrates benefits for precast elements, their integration is considered challenging and complex (XU et al., 2018). Besides, the development of applications for quality inspection and improvement of assembly follow-up are identified as necessary (LI et al. 2018).

Aiming to meet these needs, a cloud-based platform that integrates BIM, IoT, and RFID to support the logistical management of precast concrete elements was developed. For this, the methodology used was Design Science Research (DSR). According to Bax (2014), DSR involves constructing, investigating, validating, and evaluating artifacts, searching to solve new practical problems. Section 2 presents a literature review seeking to highlight the main aspects related to the integration of BIM, IoT, and RFID used in precast concrete systems. Section 3 explains the steps of the DSR methodology, which are awareness, suggestion, development, evaluation, and conclusion. Section 4 presents the development of the system, its use in a field study, in addition to an evaluation carried out by users, demonstrating its features and potential. Discussions and conclusions are covered in section 5.

The platform developed can be understood as a system composed of an RFID reader, a mobile application, and a website. This research seeks to study the benefits of this integration for logistics management, which comprises the records of quality inspection processes in production, transport, and assembly stages, communication between the parties involved, and assembly monitoring. The innovation of this research is in the development of a platform integrating BIM and IoT to improve quality inspection processes and increase user perception in the assembly stages through comparative reports using two BIM models, one for the planned and another for the executed.

2. LITERATURE REVIEW

The use of BIM and technologies such as IoT, RFID, and Cloud Computing in the stages involving prefabricated concrete elements has been conducted by few researchers and professional communities since this is a new subject to be explored. Nevertheless, this integration has shown significant benefits for logistical processes and contributes to maintenance, carbon emissions analysis, and energy consumption.

According to Eastman et al. (2014), BIM presents solutions under constant development, and prefabricated systems can obtain considerable gains in their applications. Each modeled component has details such as its 3D geometry, finishing and material information, date records before and after manufacture, among others. Furthermore, with the emergence of communication alternatives, the use of these technologies tends to grow more and more, becoming an everyday activity in the field worker's daily life (EASTMAN et al., 2014).

According to Vermesan and Friess (2013), the Internet of Things offers solutions based on integrating information technologies, considering the hardware and software used to archive, retrieve and process data. In this context, electronic systems allow the interconnection of machines, devices, and people through the Internet, allowing the creation of data that can generate analytical perceptions and support the decision-making process (NORD, j. H; KOOHANG, A .; PALISZKIEWICZ, J. 2019; VERMESAN; FRIESS, 2013). The study by Xu, He, and Li (2014) presents an IoT infrastructure organized into layers, which are the sensing, network, service, and interface layers. In this structure, layers are used to determine the function of each group and propose a relationship between them. (XU; HE; LI, 2014).

Shahinmoghadam and Motamedi (2019) argue that integrating IoT and BIM is carried out through remote sensing and physical control of objects within a construction site or an existing facility through continuous real-time data communication.

As Dolgui and Proth (2008), RFID is a wireless technology that enables automatic remote identification of objects. These authors describe that the main components of an RFID system are composed of tags incorporated or attached to any object, specialized readers that read through from antennas, and a processing device (WANT, 2006; COUTO; MALAFAIA, 2019).

The integration of these technologies can be seen in the work developed by Li et al. (2018), where public incentives in Hong Kong were carried out to adopt these new technological alternatives. In this same study, a system was proposed that used BIM, IoT, and RFID technologies, to meet demands such as monitoring the project's progress, communication process, decision making, among other activities. Besides, other applications were made seeking to meet areas focused on carbon emission costs, energy consumption, maintenance, among others (MAO et al. 2015; HAN; YE 2018; LI et al. 2019b and QI; CHEN; COSTIN 2018).

Within the infrastructure of the Internet of Things associated with BIM, the study by Niu et al. (2016) shows that the use of technologies such as RFID tags in structural elements or physical resources can be understood as the development of an intelligent object. These new objects are categorized as improved resources, being able to detect, process, evaluate, and react (NIU et al., 2017). In this context, authors such as Han, Ye (2018), Chen et al. (2018), Feng et al. (2015), Li et al. (2018), Niu et al. (2017), Niu et al. (2016), Xu, Chen, Wei (2018), Naranje, Swarnalatha (2019), Zhong et al. (2017), have developed integration processes between BIM and IoT in the prefabricated concrete system.

The work carried out by Zhong et al. (2017) proposes applying an RFID gateways operating system, which establishes connections capable of sharing information for all parties involved. Chen et al. (2018) describe this gateway communication process as an "Intelligent gateway to bridge the gap between BIM and construction". According to these same authors, this communication is developed by integration software connecting an operating system, database, and applications. Within this perspective, studies have shown that the integrated application of BIM, IoT, and RFID technologies, enable gains in the manufacturing, transportation, and assembly processes of prefabricated concrete systems (HAN; YE, 2018; CHEN et al., 2018; FENG et al. 2015; LI et al. 2018; NIU et al. 2017; XU et al. 2018; NARANJE; SWARNALATHA, 2019; LI et al. 2019).

Observing the applications focused on digital representations together with Cloud computing, the work carried out by Zhang et al. (2019) shows a structure that integrated static and variable parameters of a BIM model in a relational database, seeking to meet the needs of data management in the real environment of a building. In this study, it was observed that the authors used a model developed in the REVIT software and later used an Autodesk application program interface (API), the Forge, as a tool for visualizing the Digital model, thus establishing bidirectional communication with the database. In the study by Succar and Poirier (2020), it was observed that these digital models meet the need to continuously synchronize Digital Assets and their physical representations, which can be called Digital Twin. In this context, Zhang et al. (2019) used the database as the central structure for exchanging data between the digital twin and the information collected by sensors and actuators.

Although there is already some research on developing the integration and analysis of BIM, IoT, RFID, and Cloud Computing with prefabricated systems (FENG et al. 2015; LI et al. 2017; ZHONG et al. 2017; ZHONG et al . 2015; ZHAI et al. 2019; HAN, YE, 2018; LI et al. 2019b; QI, CHEN, COSTIN 2018), most of these studies have different models, characterizing a lack of standardization in the processes (XU et al. 2018), lack of practical studies, either in the field or prototype (MAO et al. 2018; LI et al. 2017; NIU et al. 2017; FENG et al. 2015; ZHAI et al. 2019).

Currently, no platform offers solutions using BIM, IoT, and RFID to support quality inspection during the production, transport, and assembly stages. This study seeks to develop this application and optimize the assembly process, bringing improvements through cloud computing and Digital Twins.

The conceptual structure presented in **Figure 1** represents a synthesis of the main points considered in this work, seeking to improve the management of the logistical processes of precast concrete systems through the integration of technologies coming from Industry 4.0 in line with the BIM approach.

Figure 1 seeks to concisely align the integration process, presenting four groups: (1) The Construction industry, with a focus on precast concrete systems; (2) BIM approach, with an emphasis on custom uses of the model; (3) Industry 4.0, focusing on Cloud computing, IoT and RFID; (4) the integrated system, presenting the application potentials. This last group seeks to bring the applications identified in the literature review, which align with the present work's objectives, namely traceability, logistics management, planning, communication between sectors, quality inspection, and assembly registration.

Still, in Figure 1, we sought to indicate the performance of each technology employing dashed arrows, pointing out that the use of BIM operates in the IoT interface layer, cloud computing performs functions in the service and interface layers, as well as RFID technology, acts on the sensing layer, referring this integration process to the infrastructure suggested by authors Xu, He and Li (2014).

3. RESEARCH METHOD

Following the steps described in the DSR methodology, the research was divided into five main phases, as outlined in **Figure 2**. This outline sought to relate each phase with their respective activities, explained in the following topics.

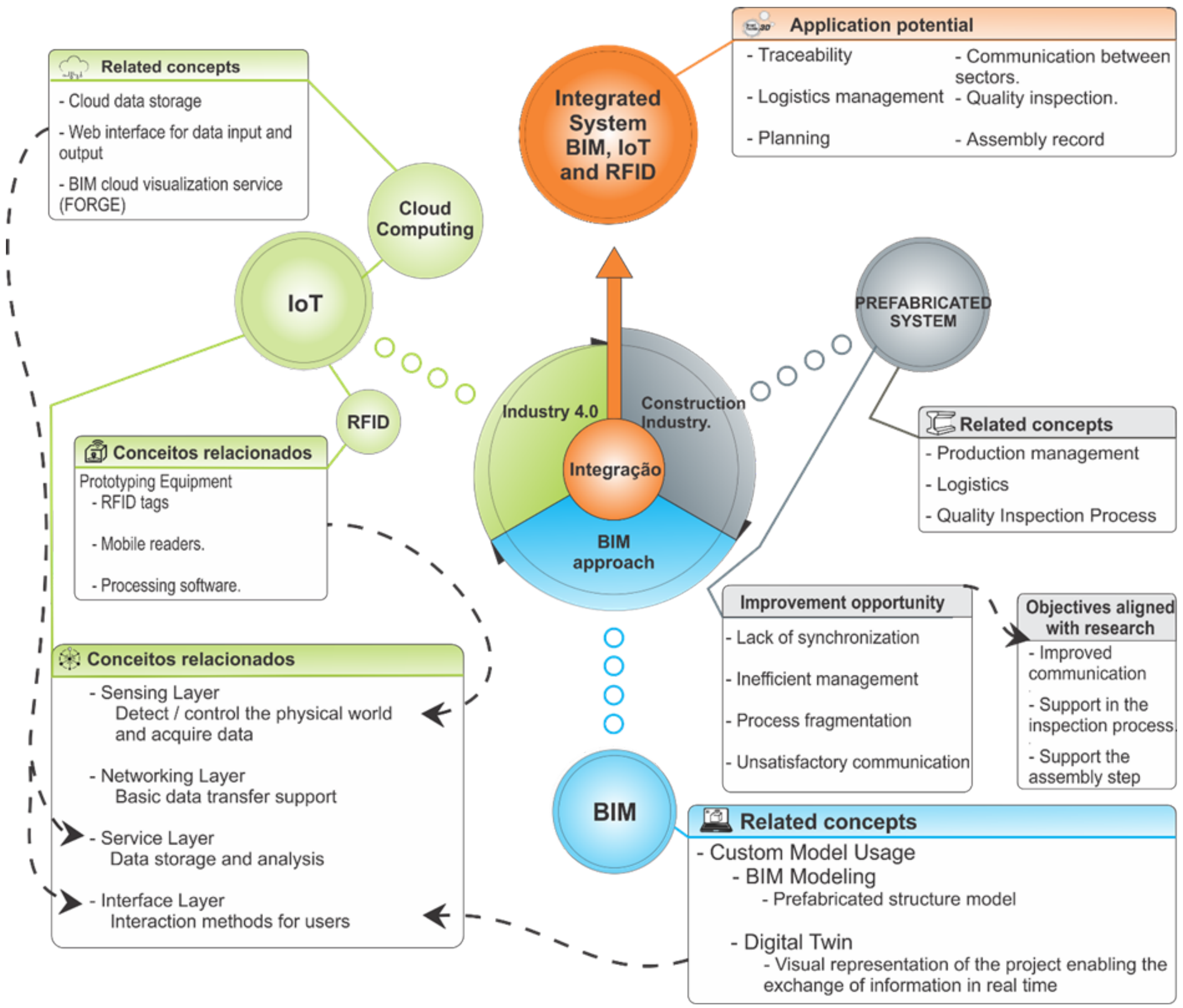


Fig. 1. Conceptual Framework

The awareness and suggestion phase contributed to the initial understanding of the study, consisting of a literature review, which identified the gaps to be studied and the technological tools used by other authors. Then, exploratory field studies were conducted through interviews with employees of three prefabricated factories, defining user requirements. After identifying the necessary tools for the development of the system and the user requirements, tests were carried out to verify the possibility of integrating BIM, IoT, and RFID technologies.

The artifact was developed using the concepts discussed in the conceptual framework presented above and the exploratory study results carried out during the suggestion phase. For this, this phase was carried out in two stages. In the first stage, requirements were defined, and the prototype in its test version was built. In the second stage, practical studies were carried out in the laboratory and the field, contributing to the process of validation and verification of the system's functioning, observing the benefits associated with quality inspection, assembly support, and communication between users.

In the artifact evaluation phase, the artifact's behavior regarding the expected results was observed. For this, constructs and variables were defined as the initial activity. Authors Martins and Pelissaro (2005) report that to carry out an exploratory process of theoretical concepts in a practical way, it is necessary for the researcher to interpret the generic view of the studied concept about the real world, basing itself on observable variables and phenomena and measurable, that is, developing constructs and operationalizing them. Based on the constructs and variables, questionnaires were prepared for employees of company B's quality inspection and planning teams, who accompanied the development and application of the system in the field study. The questions prepared for each team used the Likert scale as a reference, seeking to address the aspects of the system in general and the specific features aimed at the respondents' area of expertise. The quality sector employees who participated in this stage were three interns and one Quality Assistant. The planning sector collaborators who participated in this stage were two civil engineers and a technical assistant. The conclusion stage corresponded to the synthesis of the main lessons learned and the demonstration of evidence and contributions of the work for precast concrete systems.

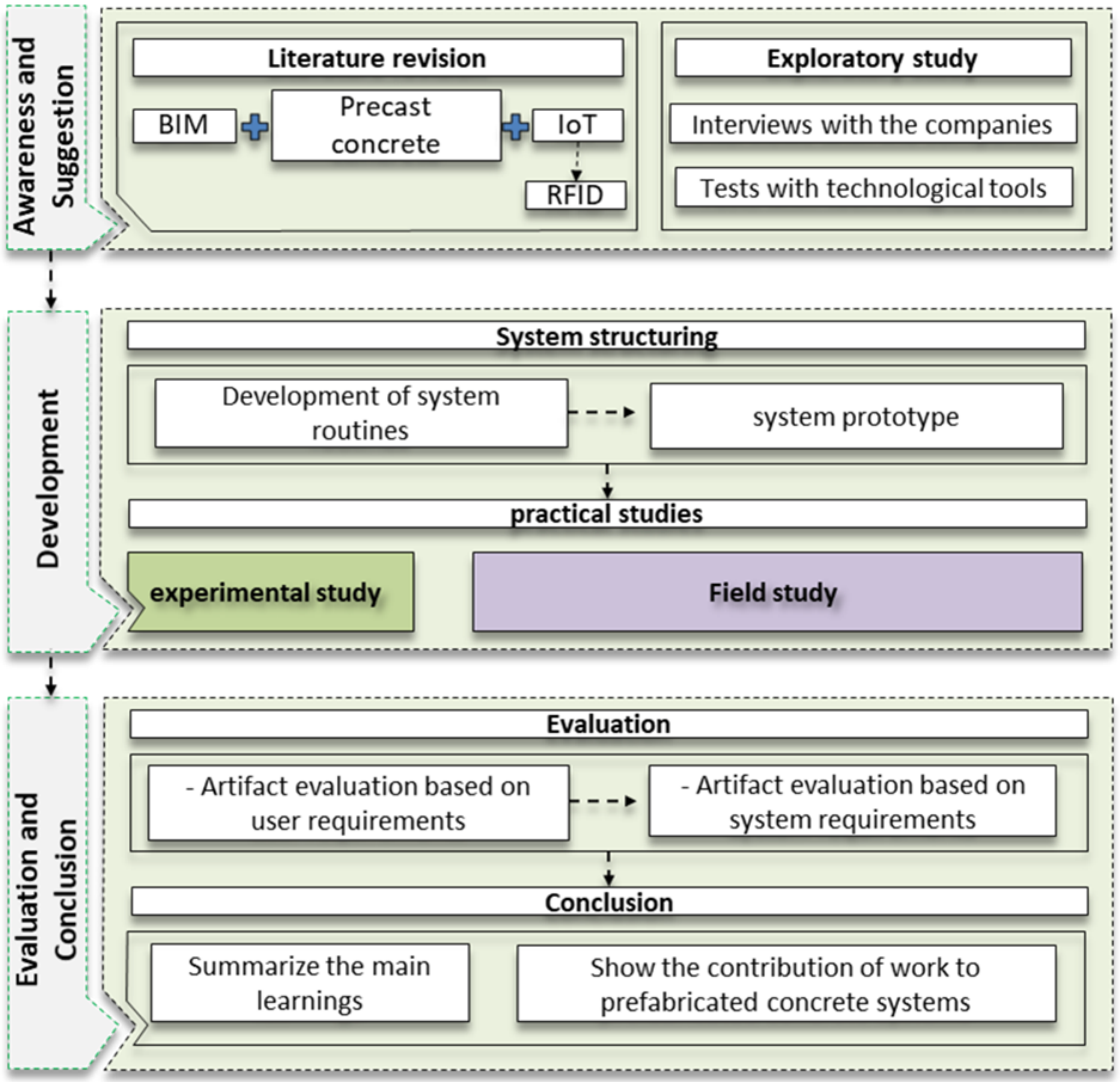


Fig. 2. Research design

4. USER REQUIREMENTS AND PLATFORM DEVELOPMENT

The identification of user requirements was carried out through exploratory visits to three factories, seeking to verify the information necessary to monitor the logistical processes of precast concrete elements. During these visits, data were collected through interviews with the prominent people responsible for the elements' production, transportation, and assembly. Based on the information collected from the companies and the literature review, the proposed platform was developed.

4.1. User requirements

The studied companies, named in this work as Companies A, B, and C, have a comprehensive portfolio, producing small and large prefabricated elements, presenting solutions through reinforced and prestressed concrete. The choice by these companies was due to their logistical management capacity to cover the stages of production, transport, and assembly of the prefabricated elements. In addition, it was observed that companies A and B have automated processes using integrated production systems, while company C has manual processes using papers and spreadsheets.

Although each company has different criteria for monitoring its processes, all reported the need for improvement in their monitoring processes. The interviews were conducted with seven engineers and two building technicians, as shown in **table 1**.

Table 1. List of companies and workers interviewed

Company	Worker	Position
A	2	Engineers
B	3	Engineers
	2	building technician
C	2	Engineers

In the study carried out with companies A, B, and C, it was identified that the sectors of Planning, Production, Quality, Assembly and the Customer are the main ones involved in this flow of information that comprises the logistical processes of the stages of production, transportation, and assembly.

In this sense, these sectors were identified as users of the system, and **Table 2** shows the general control points of companies', making a relationship between each sector with the desired specific information.

Table 2. General control points of companies

Users	Desired information
Planning/Production/Quality/Assembly	Parts in production
Planning/Production	Volume of concrete used
Planning/Production	Steel weight used
Planning/Production/Assembly	Parts at the construction site
Planning/Production/Assembly/Client	Assembled parts
Production/Quality	Error rate
Production/Quality/Client	Technological control

The desired information is understood as the data most requested by the companies and identified as necessary for the logistical process. The description of each item can be found below:

- Parts in production: this information was relevant as it helps the planning, production, and quality sectors to have daily control of the factory's progress service. For the assembly sector, the relevance of this information is identified at the time of weekly planning, as it is essential to know which parts are ready for assembly.
- Volume of concrete used: This information is directly linked to the planning and production sector since the requirement for inputs such as cement, gravel, and other components are related to the volume of concrete used.
- Steel weight used: the weight of the steel used is a value that helps in the purchase requisition of this input. Therefore, this information becomes vital for the planning and production sector.
- Parts at the construction site: this information assists the production sector in planning the transportation of parts, as the stock of parts on-site is not a good practice for activities. For the assembly sector, this information assists in planning the assembly diary and the requirement to transport new parts.
- Assembled parts: this information is of great relevance since it determines the progress of the construction of the structural elements. For the planning, production, and assembly sectors, this information assists in planning the shipment of new parts and manage stock on-site, when necessary. For the Client, this information represents the security that his enterprise is being executed as planned.
- Error rate: this information helps the quality and production sectors to report which stage of the production is with possible problems and thus improve decision making. These improvements can be achieved through training in the team that most showed errors or a possible substitution.
- Technological control: this information is initially directed to the quality and production sector, as these sectors are responsible for releasing the concreting and unshaped parts, which require the registration of the tests of axial compression, slump, and moisture correction of the parts. This information is also of great importance for the customer, as this is how he identifies if the parts received were manufactured with the requested quality.

It was observed that the information collected during the interview process with the professionals was of fundamental importance for identifying the general points of control of the stages of production, transportation, and assembly.

It was also observed that these control points are often shared by more than one sector and that one of the problems presented by companies, mainly by company C, was the lack of synchronization of these data since each sector ends up doing its survey generating duplicate information and rework.

Finally, it was found that the production sector was involved with all stakeholders and that this sector will be the primary user of the control panel. In this sense, it was decided to create a platform to help with the quality inspection processes, communication between the parties involved, and assembly monitoring.

4.2. Platform structure

The developed platform, called Smart Tracking 3D, generally comprises a web platform, a mobile application, and a database. The structure represented in Figure 3 presents the technological tools used to develop the platform and establishes a relationship with the information collected about logistics management presented in the user requirements topic.

As indicated in **Figure 3**, the sensing layer used RFID tags attached to the physical model to become a traceable object. The reading system consisted of an RFID reader (**Figure 4**) and a mobile device, along with the developed application. Thus, it became possible to collect data during all activities related to the stages of production, transport, and assembly, by reading the tags. It is noteworthy that reading the tags has the function of identifying each element uniquely; however, the information regarding logistical management, quality inspection, and assembly registration will be entered by the employee through the application.

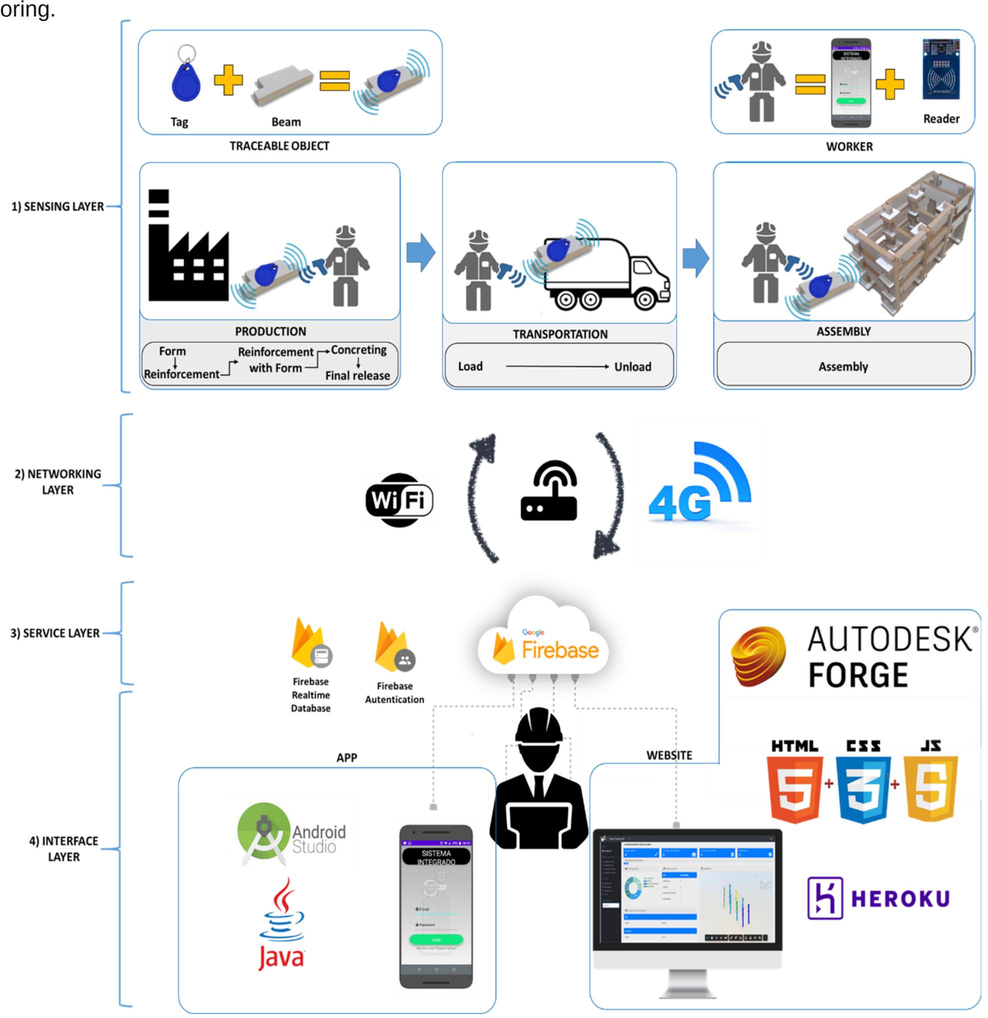
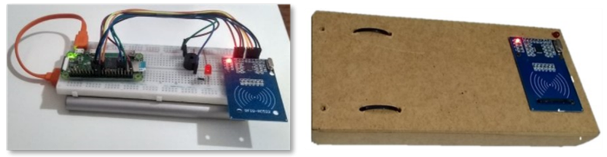


Figure 3: Four-layer system representation



a) RFID reader b) RFID reader with protective case

Figure 4: RFID Reader (Prototype)

The networking layer aims to establish a real-time connection between the sensing layer and the service layer, thus enabling the sending and receiving of data over the internet. Similar to the study carried out by Kuo, Lee, and Hsieh (2019), the cloud database functions as the system's central repository since all collected information was stored and accessed by it. For computing services performed in the Cloud, Firebase was the platform that enabled the exchange of data in real-time through a non-relational infrastructure (**Figure 5**), acting as the system database and acting in the authentication process of registered users. As shown in **Figure 5**, the database structure is made up of branches and nodes that serve for data to be stored. This organization uses Javascript Object Notation (JSON), allowing its objects not to be limited to columns and rows.

For the system's proper functioning, the database needed to be structured in the best possible way, using the recommendations offered by google, its developer. In this sense, this structuring step took time to reach its final version since data input and output performance are directly linked to the chosen structure. One of the practices that contributed to the system's best performance was to avoid nesting since the NoSQL database uses a JSON tree, being possible to nest data through nodes in up to 32 levels. It was observed that the more data that was nested, the longer it took for the system to update both in the app and on the website. In this sense, the database structure was developed simplified to reduce the number of nodes and levels used. In this regard, the present study contributed to the recommendations made by Tang et al. (2019), with tests being carried out with the non-relational database and verifying its functionality for applications in the integration of BIM and IoT.

```
129b8d26
12a3b026
  montagem
  producao
    armacao
      AlcaDelcamento: "1"
      amarracaoDasBarras: "1"
      bitola: "1"
      data: "2020-05-11"
```

Fig. 5. Database Firebase

The service layer still has the applications of the FORGE ecosystem, which prepares the BIM model to be visualized in the interface layer (ZHANG et al., 2019).

The interface layer provides interaction methods for users, consisting of an App and a web platform. It is observed that the application (Figure 3) is present in the interface and sensing layers, indicating that its application helps the user in the interaction during data collection and in accessing relevant information for monitoring the parts. The web platform allows the user to follow the progress of the production, transport, and assembly stages through a Dashboard, Digital Twins, in addition to quality inspection reports and assembly follow-up.

Application

The application's functionalities were structured in modules, enabling organized access to the system's user settings, RFID reader configuration, information management, quality inspection monitoring, supervision, and reporting module (**Figure 6**).

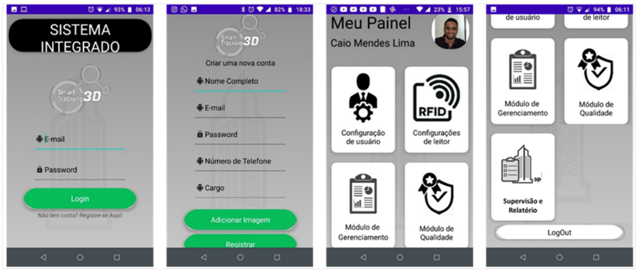


Fig. 6. Application layout

Based on this structure, the functionalities of each module can be verified in the following items:

User Configuration: This module enables the user to verify the information entered at registration, namely: name, email, telephone, title, photo, and password. In addition, the information can be changed by the user if necessary. It is noteworthy that the user's access type is assigned in the management module, presented below.

Reader Configuration: The reader configuration module aims to establish a connection between the mobile device and the RFID Reading equipment. For this, a device pairing function via Bluetooth was built and a connection verification function via tag reading test.

Management module: This module was built to record the information that enables the system to function, being inserted project data for each monitored project and data referring to the factory and its transport logistics. Selected items were pre-registration, job registration, warehouse management, vehicle registration, user access adjustment, and PDF management. It is noteworthy that the user configuration was created to establish access limits, classified as administrator or user, in which only the administrator has access to the management module.

Quality module: This module has the function of recording the inspection process of each stage that involves the production, transport, and assembly of prefabricated parts. This function consists of reading the labels attached to the parts and then filling out a verification checklist for the step in question and recording observations and non-conformities identified by the user. In addition, this module provides access to records of non-conformities, thus enabling their correction. Finally, it should be noted that the activity performed by this module is responsible for notifying the change of status of the parts, enabling the system to monitor each step performed.

Supervision and Reporting: This module was developed to allow the user to perform quick searches on registered parts by reading the label or a list provided by the application. In addition, this module allows the user to access the website, which makes the Digital Twin available for general monitoring of the project, reports, and other information.

WEB PLATFORM

The structure of the web platform was designed to present an organized interface that would provide applications aimed at registering and entering data and the visualization of specific data for monitoring and recording prefabricated concrete parts.

Based on this structure, the functionalities of each module can be verified in the following items:

Registration of information - Similar to the management module developed in the application, the website presents an adequate structure for this activity and allows the registration of the BIM model and the planning schedule. It should be noted that the planning registration function was developed to enable the assembly follow-up report to present a comparison between planned and executed.

Logistics - This function was developed to assist in transporting parts, bringing benefits in checking to load and unload through packing slips. In addition, this document presents a list of parts to be transported on a specific date, bringing information regarding the vehicle and details of the parts.

Reports - This module presents tables with information on the parts in the production, transport, and assembly stages, seeking to provide a more detailed overview of the system's monitoring process. In addition, reports regarding quality inspection and assembly follow-up can be generated.

Dashboard - This control panel (**Figure 7**) has relevant functions for the system, as it seeks to present a transparent and straightforward view of the logistics management of the prefabricated structure. For this, resources were developed that help access information about the current status of the parts, the volume of concrete used, the quantity of steel used, table and list of non-conformities, assembly monitoring, and access to the project's Digital Twin. In addition, this 3D model has a relevant role in this module, presenting specific functions for tracking structures mainly through the colors established for each status.

Erro	Quantidade
ARMACAO	2
FORMA	2
ARMACAOCFORMA	1
EMBARQUE	2

Fig. 7. Dashboard

The applications carried out on the dashboard were developed using HTML5, CSS3, and JavaScript, and their hosting in the cloud was carried out using the free Heroku platform.

The use of web platforms to assist in sharing 3D models and information from the database was of fundamental importance for the functioning of the proposed panel. Thus, web hosting services were used, which enabled the development, execution, and operation of applications entirely in the cloud. Furthermore, this web-based access interface was designed to function as a device for exchanging information between the user and the system, which instantly presents the collected data and visualizations of the BIM model.

The Computer Services performed by Forge aimed to expand the potential of the BIM model, allowing online representations of the models in the system and enabling the visualization of prefabricated concrete structures on the web interface. Among the services used, tools were customized to be used to visualize the model, allowing the creation of functions such as changing the color by updating the database and dynamic panels with information on each piece.

As can be seen in **Figure 7**, the control panel has five areas, each of which plays a fundamental role in monitoring the production, transport, and assembly of the prefabricated elements. The first area on the left side acts as the main menu for more detailed information if the user needs to explore the data further. The second area at the top presents the instant information of the location of the parts, besides presenting a general progress bar of assembly of the enterprise. The third area at the middle was reserved for presenting the data referring to the non-conformities reported by the production and quality team, displaying this data through a table and a pie chart. The fourth area at the bottle displays information regarding the consumption of steel and the volume of concrete. Finally, the fifth area on the right side represents the BIM model, intended to assist in visually monitoring the status of parts and the progress of assembly.

The Digital Twins presented on the panel seeks to inform the current status of each piece through the change of colors, in addition to providing detailed information about each element through a model monitoring panel. This status monitoring through colors used light blue for parts in production, dark blue for parts in factory stock, yellow for parts in transport, green for parts in stock at work, and gray for parts mounted. It is also noted that the parts not yet manufactured were represented transparently. In this sense, the user can visualize which part was produced, transported, or assembled and locate its position through the BIM model in real-time.

Another function associated with the Digital Twin is the model monitoring panel. Access to this panel is when the user clicks on a part, showing the information associated with the selected object, displaying the name, weight, volume, and showing progress bars of the status of the production, transport, and mounting. Therefore, this panel helps the user identify the part's specific information that has undergone a status change.

5. PRACTICAL STUDIES

For the use of the system developed in a real case, it was necessary to carry out tests through simulations in a mockup, seeking to verify its functionalities and thus be used safely and with all its attributions operating as expected. This initial test step improves the system, with adjustments being made before use in the field.

To carry out the field study, a project named in this study as Work 02 was used. This Work 02 corresponds to a building that used prefabricated concrete structural elements produced and managed by Company B, which the researcher could accompany in person. This structure is formed by 50 pillars and 88 beams, totaling 138 pieces. It is important to emphasize that although this project includes other structural elements such as foundations and slabs, these were not manufactured by Company B.

The initial phase of system configurations used the registration module to register a new work and the parts to be produced, and the shed and vehicles used.

Then, the information regarding the production and assembly schedule in the system was released. For this, the documentation related to the planning was used, consisting of an Excel spreadsheet and an MSProject file containing each part's production and assembly dates.

Subsequently, the insertion of the BIM model in the system was performed, similarly to the experimental study.

The monitoring of the production, transport, and assembly stages was carried out mainly through the quality module, which enabled the tracking of parts during all processes.

Following the planning team's initial production schedule, the researcher followed the inspections by observing two interns from the quality team (**Figure 8**). For this, the developed system was used, with 11 non-conformities being registered.

During the use of the system, it was found that four labels presented complications during its handling, in which the P19 label suffered a slight melting of the plastic bag due to the cutting and welding equipment of the forms (Figure 9 (a)), without compromising its integrity, the P20 tag stopped working due to impacts while moving parts in stock (Figure 9 (b)), the P21 tag was lost (Figure 9 (c)). Finally, the P34 tag was crushed (**Figure 9**(d)), but it continued to work. It is noteworthy that the P20 and P21 tags were replaced so that the follow-up could be carried out in the later stages.


a) Tag reading b) Pillar reinforcement c) Reinforcement with Form

Figure 8: Inspection process


a) P19 b) P20 c) P21 d) P34

Figure 9. Inspection process

This inspection proposal contributed to reducing the use of daddies during this process, real-time monitoring of the production, transport, and assembly stages, and improving the reports through the addition of photographic records of the non-conformities found. However, for the construction of this equipment, some difficulties were encountered, such as the instability of the connection between the reader and the application, poor contact between the connection circuits of the side and buzzer, in addition, to delay in updating the information due to connection failure, since the system is 100% online. However, the obstacles related to the connection between the reader and the application and the circuits were overcome during the development process. At the same time, the delays in updating the information were directed to future work, requiring the development of an offline system. However, this study contributed to developing a system with applications aimed at quality inspection in precast concrete systems, based on the gaps found in work by Li et al. (2018).

In order to carry out the transport stage, which consists of recording the loading and unloading, the monitoring was carried out at the receiving location, enabling the registration of parts in stock and of assembled parts.

Similar to the activities carried out in the experimental study, the data analysis step, which corresponded to monitoring information on the logistics, quality inspection, and assembly process via the web, was initially carried out through the dashboard, which enabled the verification of these steps in real-time. As a result, the information presented in the Digital Twin corresponded with the activities found in the field. Other data verified in the dashboard were the inspected items, which corresponded with the records previously carried out in the production stage. However, the information regarding the consumption of concrete was different from the values found by company B. This inconsistency was caused by design errors, which were not passed on to the researcher during the study. In addition, the top part of the dashboard was updated as previously suggested by the planning engineer, and its ability to display information that contributed to the identification of the status of the parts was verified. Finally, the function referring to the assembly progress bar presented the value 55.72%, correctly corresponding to the 70 pieces assembled on the corresponding date.

Regarding the contributions of the Digital Twin, it was possible to verify that the identification of the status of the pieces through the colors allowed a better understanding, especially of the pieces in stock at work, being in color sells(**Figure 10**). Furthermore, **figure 11** shows that the digital twin allowed, among other possibilities, the visualization of the possible parts to be assembled on a given day since the parts in stock at work are indicated in the model.

Fig. 10. Digital twin corresponding to the assembly process at the construction site.

After verifying the operation of the dashboard in the field study, the functionalities of the quality inspection report and the comparative assembly report were verified, seeking to monitor these steps in more detail and analyze the information provided.

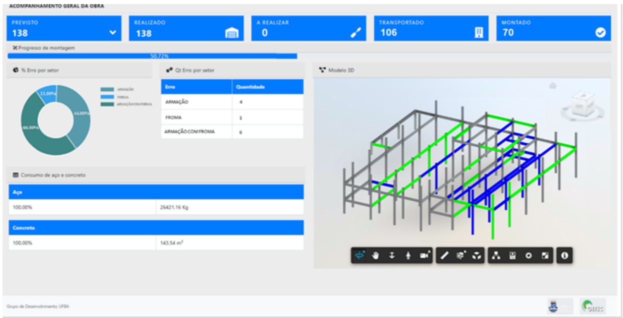
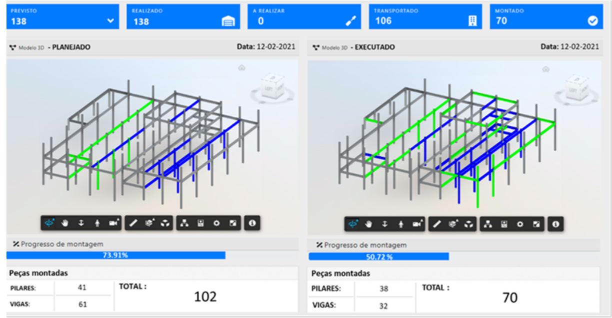


Fig. 11. Results displayed on the dashboard

It was observed that the quality inspection report presented the information correctly, showing the observations made during the inspection and enabling the visualization of the photographic. In addition, this module makes it possible to export the report in pdf, but without inserting photographic records.

The assembly report was used to verify the information of the comparative assembly process, enabling the visualization of two BIM models, one representing the information about the planning through the previously registered schedule and the other showing the information about what was performed using the collected information in real-time, as shown in **Figure 12**. It was observed that the report presented a good view of the proposed objective.


PREVISTO 138
REALIZADO 138
A REALIZAR 0
TRANSPORTADO 106
MONTADO 70

Modelo 3D - PLANEJADO Data: 12-02-2021
Progresso de montagem 73.91%
Peças montadas
PILARES: 41
VIGAS: 61
TOTAL : 102

Modelo 3D - EXECUTADO Data: 12-02-2021
Progresso de montagem 50.72 %
Peças montadas
PILARES: 38
VIGAS: 32
TOTAL : 70

Fig. 12. Assembly report

After completing the field study, the results achieved were presented to the collaborators involved during the research to start the system evaluation stage, according to the following topic.

For the assembly follow-up process, communication between the planning department and the assembly team is essential, requiring constant updating of information about what was assembled and what should have been assembled. The development of the visual tracking feature through two BIM models, one model used to represent the real-time status of the construction and the other to represent what was planned, brought significant contributions, reducing the manual work of the conference performed by the planning team and assisting the assembly team in checking the parts on site. The main challenge for this activity was to efficiently structure the database so that the system would not take a long time to represent the planned model. It was found that the system worked as expected, but it can present delays in the representation of the model in works with a larger number of parts. However, it is observed that this research contributed to the advancement of studies carried out by Li et al. (2018), who sought to develop this activity through graphics associated with a monitoring model.

6. Evaluation and discussion

This topic presents the evaluation of the results obtained during the application of the system in the experimental study and the field study. This evaluation was carried out based on the Functionality, Utility, and Transparency constructs, which helped to understand the operational aspects of the system and the perception of users through the answers to Questionnaires.

The evaluations on the constructs Utility and Transparency were answered by employees of company B from the quality/production sector, who were interns and engineers, and from the planning sector, engineers and planning assistants, totaling 7 participants.

Table 3. List of functions performed

	Modules	*Function*	*E. S.*	*F. S.*
WEBSITE	***Registration of information***	*User Adjustment;*	*C*	*C*
		Registration of work;	*C*	*C*
		Pre-registration of parts;	*C*	*C*
		Vehicle Registration;	*C*	*C*
		BIM model registration;	*C*	*C*
		Warehouse Management;	*C*	*C*
		PDF Management;	*M*	*C*
		Planning;	*X*	*C*
	Logistics	*Packing list.*	*C*	*C*
	Reports	*List with parts information;*	*X*	*C*
		Quality inspection report;	*X*	*C*
		Assembly follow-up report.	*X*	*C*
	Dashboard	*Current status of parts;*	*M*	*C*
		Concrete volume used;	*C*	*C*
		Quantity of steel used;	*C*	*C*
		Chart and non-compliance list;	*C*	*C*
		Access to the project's Digital Twin;	*C*	*C*
APP	***RFID Reader Configuration***	*Establish Connection with the Reader;*	*M*	*C*
		Connectivity check.	*M*	*C*
	Quality Module	*Production Module;*	*C*	*C*
		Transport Module;	*C*	*C*
		Assembly Module;	*C*	*C*
		Error reporting.	*C*	*C*
READER	***RFID Reader Prototype***	*Reading distance*	*C*	*C*
		Device operation	*M*	*C*
LEGEND:	***E.S.:** Experimental Study; **F.S.:** Field study.* ***C:** Correct functioning; **M:** Moderately functioning; **X:** Under development.*			

Functionality

In this work, functionality is understood as evidence of the operations of the proposed system, seeking to identify incorrect, undesirable, or different actions than required (SOMMERVILLE, 2011).

For this evaluation, **Table 3** summarizes the points observed relating to the applications evidenced during the use of the system in the experimental and field study, seeking to verify its correct functioning through the researcher's perception and the information collected from the system. Thus, the letter "C" was assigned for the correct functioning of the system; "M" for functions that showed moderate performance and need improvement; and "X" for functions under development.

According to **Table 3**, it is observed that the version of the system used in the experimental study had functions still under development and to be soaked. However, these points were improved so that a new version was used in the practical study.

Utility

The utility construct was used to assess the user's perception of the system in adapting to their reality. The applicability of the system for logistics management and decision-making in the production, transport, and assembly stages, support in monitoring the inspection of the quality of parts, in addition to the benefits and difficulties associated with the system's potential, was identified.

For this, three questions were asked to the study participants: (1) How do you rate the system's ability to provide an overview of the work through the Dashboard and Report? (2) How do you perceive the BIM model's ability to display the actual status of parts in the production, transportation, and assembly stages? (3) How do you assess the system's ability to assist in decision-making regarding the production, transport, and assembly of prefabricated elements? (4) How do you rate the monitoring of the quality inspection of parts by the application? (5) How do you assess the system's ability to record and display non-conformities after the quality inspection? (**Figure 13**).

According to the graph shown in Figure 13, it was observed that the score given to the first question was 4.57, showing that employees found the system very useful for providing an overview of the work through the dashboard and reports. The second question analyzed was the ability of the BIM model to display the actual status of the parts, which is considered very useful by all employees, having a grade of 4.71. The third question investigated the system's ability to assist in decision making, which was considered very useful, both by the quality inspection team and the planning team, with a score of 4.57. Finally, the fourth and fifth questions were rated 4.75, respectively, showing that the inspection process and the system's ability to record and display non-conformities were considered very useful.

The identified benefits showed (**Table 4**) that the participants recognized the potential associated with the main features of the system, namely: contribution to the quality inspection process; communication between different sectors; and support in the assembly process. On the other hand, the difficulties identified showed, for the most part, points not yet worked on in this study, contributing to the process of later improvement of the system.

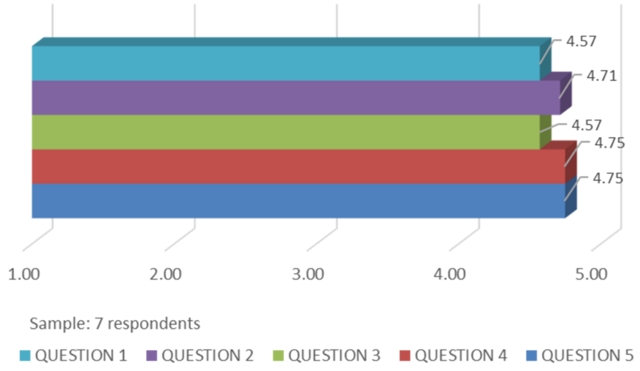


Fig. 13. Assessment of the utility construct

Table 4: List of benefits and difficulties found

Benefits	**Difficulty**
• Better monitoring of the assembly process; • Reduction of work related to the location of parts in stock at the factory and in the field; • Better quality inspection process due to photographic records; • Best way to show the results achieved to the board; • Sharing the results with the production and assembly team; • Best way to display the results to the client; • Improvement in the assembly plan; • Speed in identifying information.	• Resistance to use the system due to the employees' culture; • Problem in manipulating the BIM model due to little familiarity with the interface; • Need for a collaborator for the development of the BIM model; • View the part name in the 3D model; • Need for more detailed information in the assembly report.

Transparency

The transparency construct included the evaluation of the following variables:

- quality of communication between the stages of production, transport, and assembly based on the use of the proposed system;
- a better understanding of the assembly progress through the report comparing what was planned and executed;
- simplicity in understanding the information.

For this, questions 6, 7, 8, and 9 were performed for the study participants, as follows: (6) How do you rate the system's ability to improve communication between the Production/Quality Sector and the PCP? (7) How do you rate the system's ability to improve communication between the PCP and the assembly? (8) How do you classify the system's ability to display the comparison of planned and excepted? (9) How do you rate the simplicity in understanding the information presented by the presented system? (**Figure 14**).

According to the graph in Figure 14, it is observed that questions 6 and 7 obtained a score of 5.00, respectively, showing that the system was considered very useful in supporting communication between sectors. The score given to question 8 was 4.67, revealing that the system's ability to compare planned and executed activities through the Digital Twin was considered very useful. Finally, question 9 received a score of 4.29, showing that the collaborators rated the simplicity in understanding the information as very satisfied.

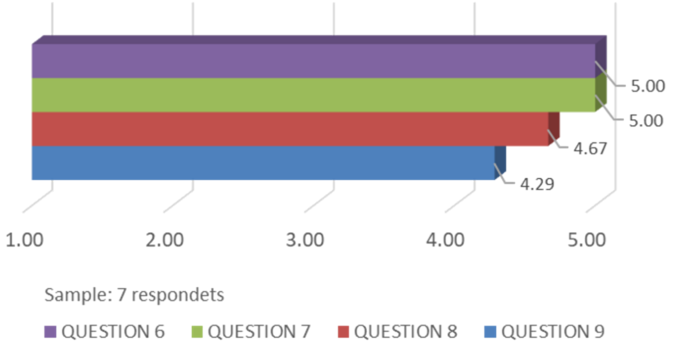


Fig. 14. Assessment of the Transparency construct

7. CONCLUSION

The prototype of the system developed, called Smart Tracking 3D, helped in the management process of the production, transport, and assembly stages, mainly enabling the tracking of elements, quality inspection records, visualization of data collected through the dashboard and digital twin, in addition to generating inspection and assembly follow-up reports.

The integrated system development process initially required exploratory research conceptually, identifying gaps and technological tools through a literature review. This phase contributed to elaborating a conceptual structure, which brings together the concepts of BIM, IoT, and prefabricated systems, aiming to build an integrated system.

For the system integration process, it was observed that cloud computing contributed in a fundamental way for the IoT infrastructure to be established since the Firebase database worked as the system's central repository. In this sense, the established routines using the FORGE ecosystem and the Web platform enabled the Digital Twin to function as expected, noting the integration of BIM models for its personalized use in its Web version. In addition, the RFID tags and reader together with the application were essential for the physical environment to be represented in the virtual environment, contributing to the integration process of the proposed technologies.

The practical studies carried out in the laboratory and in the field resulted in verifying the functionalities of the developed system. In the experimental study, a mockup was used to carry out the tests, enabling the simulation of the system quickly and practically. Furthermore, this first test verified the integration of technologies in the context applied to precast concrete systems, thus enabling tests using actual data. The system was tested in a real situation in the field study, with the production, transport, and assembly stages being followed. From these tests, the technical functionalities of the system were validated, as well as its capacity to support the management of logistic processes in precast concrete systems.

After the tests were performed, the functional aspects of the system were initially evaluated, which showed satisfactory performance and opportunities for improvement. As it is a prototype, this evaluation was characterized as preliminary, requiring new stages of development of the artifact, seeking the construction of improved versions. Next, the system was evaluated by seven employees from the production, quality, and planning sectors, seeking to evaluate it based on the users' perception of its usefulness and transparency. It was noted that the assessment regarding utility was primarily rated as very useful and extremely useful, highlighting as a differential the possibility of the system to perform photographic records of non-conformities and monitoring the status of the parts through colors in the twin digital. In addition, the utility construct analyzed the benefits and difficulties, contributing to the identification of opportunities for improvement. The assessment of the system's transparency was rated overall as high and very high and very satisfied and extremely satisfied. Thus, it was found that the information provided by the system was transmitted, contributing to effective communication between the parties involved. Based on the evaluations, it was possible to verify that the system showed positive results in all items checked, demonstrating its capacity to carry out the proposed activities.

Despite the benefits presented, the developed platform was built with few financial resources, limiting the use of prototyping equipment, which is necessary for further studies to use commercial equipment. Another limitation can be found regarding the efficiency of the system for the use of larger projects, requiring more tests to evaluate this aspect. Finally, a new version that allows offline operation is being implemented. Despite the limitations presented, this study developed an application to inspect the quality of precast concrete elements and optimize the applications through Digital Twin in the assembly process.

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REFERENCES

Peñaloza, G. A., Viana, D. D., Bataglin, F. S., Formoso, C. T., Bulhões I. R. (2016) Guidelines for integrated production control in engineer-to-order prefabricated concrete building systems: preliminary results. Conf. of the Int'l. Group for Lean Construction. Boston, MA, USA, sect.6 p. 103–112.

Li, X., Shen, G. Q., Wu, P., Yue, T. (2019) Integration Building Information Modeling and Prefabricated Housing Production. Automation in Construction, v. 100, p. 46–60.

Naranje, V., Swarnalatha, S. (2019) Design of Tracking System for Prefabricated Building Components using RFID Technology and CAD Model. The 12th International Conference Interdisciplinarity in Engineering, Procedia Manufacturing. v. 32 p. 928-935.

Dallasega, P., Rauch, E., Linder, C. (2018) Industry 4.0 as an enabler of proximity for construction supply chains: A systematic literature review. Computers in Industry. v.99, p. 205–225.

Eastman, C.; Teicholz, P.; Sacks, R.; Liston, K. (2014) BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Manager. 2rd Edition.

Zhong, R. Y., Peng, Y., Xue, F., Fang, J., Zou, W., Luo, H., Ng, S. T., Lu, W., Shen, G. Q. P., Huang, G. Q. (2017) Prefabricated construction enabled by the Internet-of-Things. Automation in Construction. v.76, p. 59–70.

Yin, X., Liu, H., Chen, Y., Al-hussein M. (2019) Building information modelling for off-site construction: Review and future directions. Automation in Construction. v.101, p. 72–91.

Ikonen, J., Knutas, A., Hämäläinen, H.; Ihonen, M.; Porras, J.; Kallonen, T. (2013) Use of embedded rfidtags in concrete element supply chains. Electronic Journal of Information Technology in Construction. ISSN 1874-4753.

ASHTON, K. (2009) That 'internet of things' thing. RFiD Journal, v. 22, n. 7, p. 97-114.

Nord, J. H., Koohang, A., Paliszkiewicz, J. (2019) The Internet of Things: Review and theoretical framework. Expert Systems with Applications. v. 133, p. 97–108.

Vermesan, O., Friess P. (2013) Internet of things –Converging Technologies for Smart Environments and Integrated Ecosystems. RIVER PUBLISHERS SERIES IN COMMUNICATIONS, p. 348.

Zhao, L., Liu, Z., Mbachu, J. (2019) Development of Intelligent Prefabs Using IoT Technology to Improve the Performance of Prefabricated Construction Projects. Sensors. v. 19, p.1-30.

Coutinho, A. A. T. R., Carneiro, E. O., Greve, F. G. P. (2016) Capítulo6 Computação em Névoa: Conceitos, Aplicações e Desafios. XXXIV Simpósio Brasileiro de Redes de Computadores e Sistemas Distribuídos. p. 266-315.

Li, C. Z., Xue, F., Li, X., Hong, J., Shen, G. Q. (2018a) An Internet of Things-enabled BIM platform for on-site assembly services in prefabricated construction. Automation in Construction. v.89, p. 146–161.

Mao, C., Shen, Q. M., Pan, W., Ye, K. (2015) Major Barriers to Off-Site Construction: The Developer's Perspective in China. Journal of Management in Engineering. v. 31, n. 3, p. 1–8.

Han, C., Ye, H. A. (2018) Novel IoT Cloud BIM Based Intelligent Information Management System in Building Industrialization. ICCREM 2018. p. 72-77.

Qi, B., Chen, K., Costin, A. (2018) RFID and BIM-Enabled Prefabricated Component Management System in Prefabricated Housing Production. Construction Research Congress. p. 591-601.

Niu, Y., Lu, W., Chen, K., Huang, G. G., Anumba, C. (2016) Smart Construction Objects. J. Comput. Civ. Eng., 2016, v. 30.

Niu, Y., Lu, W., Liu, D., Chen, K., Anumba, C., Huang, G. G. (2017) An SCO-Enabled Logistics and Supply Chain–Management System in Construction. J. Constr. Eng. Manage. v.143.

Chen, K., Lu, W., Xue, F., Zheng, L., Liu, D. (2018) Smart gateway for bridging BIM and building. Proceedings of the 21st International Symposium on Advancement of Construction Management and Real Estate. p. 1307–1316.

Feng, C., Hu, H., xu, F., Yang, J. (2015) An Intelligent Logistics Management Model in Prefabricated Construction. Frontiers of Engineering Management. p. 178 -181.

Xu, G., Li, M., Chen, C., Wei, Y. (2018) Cloud asset enabled integrated IoT platform for lean prefabricated construction. Automation in Construction. v.93, p. 123–134.

Succar, B., Poirier, E. (2020) Lifecycle information transformation and exchange for delivering and managing digital and physical assets. Automation in Construction. v.112, p. 1–22.

Li, J.; Yang, H. (2017) A Research on Development of Construction Industrialization Based on BIM Technology under the Background of Industry 4.0. MATEC Web of Conferences. v.100.

Zhong, Y. R., Peng, Y., Fang, J., Xu, G., Xue, F., Zou, W., Huang, G. Q. (2015) Towards Physical Internet-enabled Prefabricated Housing Construction in Hong Kong. IFAC-PapersOnLine. v. 48-3, p. 1079-1086.

Zhai, Y., Chen, K., Zhou, J. X., Cao, J., Lyu, Z., Jin, X., Shen, G. Q. P., Lu, W., Huang, G. Q. (2019) An Internet of Things-enabled BIM platform for modular integrated construction: A case study in Hong Kong. Advanced Engineering Informatics, v. 42, p. 1-15.

Li, C. Z., Hong, J., Xue, F., Shen, G. Q., Xu, X., Luo, L. (2016) SWOT analysis and Internet of Things-enabled platform for prefabrication housing production in Hong Kong. Habitat International. v. 57, p. 74-87.

ABOUT AUTHORS

Caio Mendes Lima, B.Sc, Federal Institute of Sergipe (IFS), Aracaju, Brazil, and held academic exchanges at Arizona State University, ASU (United States), 2013-2014. His MSc in Civil Engineering from Federal Institute of Bahia (UFBA), Salvador, Brazil. He performed work related to tracking precast elements, through BIM and IoT integration using RFID and non-relational databases stored in the cloud. His research interests include project management; management information system, automated inspection, decision-making support, logistical aspects, Building Information Modeling, and Internet of Things.

Emerson de Andrade Marques Ferreira is a Professor at UFBA - Federal University of Bahia(UFBA), Salvador, Brazil. He received his BSE in civil engineering from UFBA; his MSc in Architecture from the University of São Paulo, São Paulo, Brazil; his Ph.D. in civil engineering from the University of São Paulo, São Paulo, Brazil. His research interests are in the area of Management, with an emphasis on Production Management, working mainly on the following topics: planning and control, construction site, sustainability, work safety, feasibility analysis, information technology, and BIM.

João Luiz Calmon is a Professor at UFES - Federal University of Espirito Santo), Vitória, Brazil. He received his BSE in civil engineering from UFES; his MSE in Production Engineering from Catholic Pontific University, Rio de Janeiro, Brazil; his Ph.D. in civil engineering from Catalonia Polytechnic University, Barcelona, Spain; and his Post-Doctorate degree from Eduardo Torroja Institute for Construction Science, Madrid, Spain. His research interests include project management; cleaner production; Finite element method applied to construction processes and structures – Thermal stress (dams, large foundations); high temperatures in structures; concrete technology, durability of structures, use of waste and industrial by-products as building materials, sustainable construction.