Intelligent Materials Tracking System for Construction Projects Management*

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Abstract. An essential factor adversely affecting the performance of construction projects is the improper handling of materials during site activities. In addition, paper-based reports are mostly used to record and exchange information related to the material components within the supply chain, which is problematic and inefficient. Generally, technologies (such as wireless systems and RFID) are not being adequately used to overcome human errors and are not well integrated with project management systems to make tracking and management of materials easier and faster. Findings from a literature review and surveys showed that there is a lack of positive examples of such tools having been used effectively. Therefore, this research focused on the development of a materials tracking system that integrates RFID-based materials management with resources modelling to improve on-site materials tracking. Rapid prototyping was used to develop the system and testing of the system was carried out to examine the functionality and working appropriately. The proposed system is intended to promote the employment of RFID for automatic materials tracking with integration of resource modelling (Microsoft ® Office Project) in the project management system in order to establish which of the tagged components are required resources for certain project tasks. In conclusion, the system provides an automatic and easy tracking method for managing materials during materials delivery and inventory management processes in construction projects.

Keywords: *construction projects; integration; materials management; materials tracking, RFID*

1 Introduction

Materials management is defined as a coordinating function responsible for planning and controlling material flow [1]. It includes planning and taking off materials, vendor evaluation and selection, purchasing, expenditure, shipping, materials receiving, warehousing and inventory, and materials distribution [2]. Bell & Stukhart [2] also stated that it is important for planning and controlling of materials to ensure that the right quality and quantity of materials and

Received April 2nd, 2014, 1st Revision July 26th, 2014, 2nd Revision December 1st, 2014, Accepted for publication May 11th, 2015.
 ISSN: 2337-5779, DOI:10.5614/j.eng.technol.sci.2015.47.2.11
*Part of this paper has been presented in The 2nd International Conference on Sustainable Infrastructure & Built Environment (SIBE), 19-20 November 2013, Bandung, Indonesia.

installed equipment are appropriately specified in a timely manner, obtained at a reasonable cost, and are available when needed. Many construction projects apply manual methods, not only for the tracking of materials but also for materials management as a whole and this involves paper-based techniques and is problematic with many human errors occurring [3].

Implementation of information and communication technology (ICT) in materials management has the potential to significantly improve the management of materials on site. According to a Building Research Establishment report [4], ICT applications in the construction industry are now commonplace for facilitating procurement, collaboration and knowledge management. For example, product procurement has such features as direct and indirect purchasing, electronic payment and material aggregation that can be supported by ICT. This can eliminate paperwork, lower product and operational costs, and reduce cycle times. ICT is used in materials management for cost estimation through involving well-known software such as Microsoft Excel [5]. However, there is not much use of modern ICT tools (e.g. wireless communication, bar-coding and radio frequency identification (RFID)) to facilitate materials management processes for tracking materials quickly, accurately and easily.

Generally, tracking technologies such as wireless communication, bar-coding and RFID are not adequately employed in developing materials tracking practices for construction projects [6]. Accordingly, there is scope for significant improvement if automated tracking technologies were deployed to overcome problems in manual practices, which are labour intensive and error-prone [7]. RFID has the potential to facilitate materials management processes for large-scale projects, particularly with regard to the capability to store a large amount of data compared to bar-coding [8]. Kasim [9] state that RFID is expected to be beneficial in reducing paper-based requirements and can also be integrated with different applications such as project management systems, to make tracking and management of materials easier and faster. Therefore, this research focused on the deployment of RFID with the integration Microsoft ® Office Project to improve on-site materials tracking, inventory management processes, and resource management.

2 Requirements for Materials Tracking System

In general, the current practices in tracking materials on construction projects are undertaken manually and are excessively paper-based. Previous research projects have demonstrated the successful use of automated tracking technologies such as RFID in helping to improve materials tracking on the construction site as shown in Table 1. It is evident that there is a growing use of RFID in the construction industry and many application areas have emerged. Nevertheless, there is inadequate integration of RFID-based materials tracking with resource modelling [9].

Table 1 Research Projects on Implementation of RFID Technology.

No	Research Project
1	The development of a prototype system for identification and spatial tracking of structural steel members at the construction site [10]
2	The utilization of RFID for tracking precast concrete components and their historical information from fabrication to post construction [11]
3	The implementation of RFID (data storing) and GPS (materials positioning) to trace asphalt quality for a road-building project [12].
4	Implementation of RFID in the construction process to provide a procedure for helping contractors and owners to determine the type of RFID configuration that best fits their applications [13]
5	Automatic tracking the delivery and receipt of fabricated pipe spools in industrial projects to determine RFID feasibility [14]
6	Integrating RFID and Global Positioning System (GPS) with management tools to collect pre-fabricated pipe spool locations and identification data on handheld devices [15]
7	A model to track the progress of percentage completed in construction projects by the adoption of RFID and wireless technologies [16]
8	Development of an automated model for materials management and control with the application of RFID technology [17]
9	Integrating bar-coding and RFID to automate data collection from the construction site to track project cost and schedule information [18]
10	The application of RFID for tool tracking on construction job sites by developing a tool tracking and inventory system capable of storing operation and maintenance data [19]
11	The implementation of RFID technology to monitor planning of the materials used in a water supply project that suffers from poor materials management due to the complex operational environment [20]
12	Development of a real-time materials tracking system to improve materials tracking and the overall process of materials management on construction sites [21]
13	The identification and localization of engineering components of industrial sites using RFID and GPS [22]
14	The real-time monitoring of materials using RFID on construction sites [23]
15	Ubiquitous tracking and locating of construction resources using RFID, GPS and Geographic Information System (GIS) [24]
16	How to facilitate construction materials management and solve materials management problems using RFID and Personnel Digital Assistants (PDA) [25]
17	To investigate a new approach for integrating the latest innovations in automated data collection (ADC) technologies for real-time data collection in construction using RFID, GPS and General Packet Radio Service (GPRS) [26]
18	Efficient location tracking systems for asset tracking and safety assurance using Ultra-Wide Bands (UWB), RFID and GPS [27]
19	Information Lifecycle management with RFID for material control on construction sites [28]

A preliminary case study was used to investigate current materials management practices, problems, ICT implementation, and the possibility of using technologies (such as RFID and wireless technologies) to improve current practices. The key findings from the case study include: inadequate techniques to overcome human errors and inadequate use of modern ICT tools such as RFID to assist materials tracking [9]. An integrated framework for real-time materials tracking is required in order to provide a system for materials management on the construction site. Therefore, in this research a system was developed to integrate RFID-based materials management with resources modelling in project management.

3 Rapid Prototyping Methodology

The aim of this research was to develop a prototype system for integrating materials management and resource modelling. Initially, a framework for integrating RFID-based materials management with resource modelling in project management systems was developed. The integration framework was achieved through case study findings, supported by an extensive literature review on materials management processes and ICT implementation to facilitate materials management in construction projects. The case study helped to identify aspects of ICT implementation in materials management practices. Organisations have a variety of mechanisms for managing materials in construction projects. Nonetheless, the site managers have difficulties with regards to resolving materials management problems under current practices.

The integrated framework consists of three components:

- *Materials Registration:* Registration of construction materials used in a database system (Microsoft ® Office Access).
- *Materials Delivery*: Automatic identification for materials tracking using RFID technologies and integration with resource modelling in project management system during materials delivery to the construction site;
- *Materials Use*: Automatic identification of materials during installation at the construction site and integration with resource modelling in project management system.

The framework provides a structured approach to managing the real-time materials tracking process on the construction site. The integrated models include the integration of RFID technologies to provide real-time materials tracking and resource modelling in the project management system. The automation and implementation of the framework was the next stage.

Specifically, the intention was to encapsulate the developed real-time materials tracking framework into a prototype system. Prototyping is the process of building an experimental system quickly and inexpensively for demonstration and evaluation so that the users can better determine information requirements [29]. The aim of developing a prototype in this research was to integrate RFID-based materials management and resource modelling in a project management system (such as Microsoft ® Office Project). A rapid prototyping methodology was used in the developing of the prototype system. According to [30], the key strengths of prototyping include: short development time; short user reaction time (feedback from user); improved user understanding of the system, its information needs, and its capabilities, and low cost. Several iterations to refine and enhance the prototype can be done before continuing with the final operation, because the prototype can be developed quickly and inexpensively. Nevertheless, prototyping can gloss over essential steps in the system's development [29]. If the completed prototype works reasonably well, management may not believe there is a need for reprogramming, redesigning, or full documentation and testing to build a polished production system. The process of rapid prototyping is shown in Figure 1.

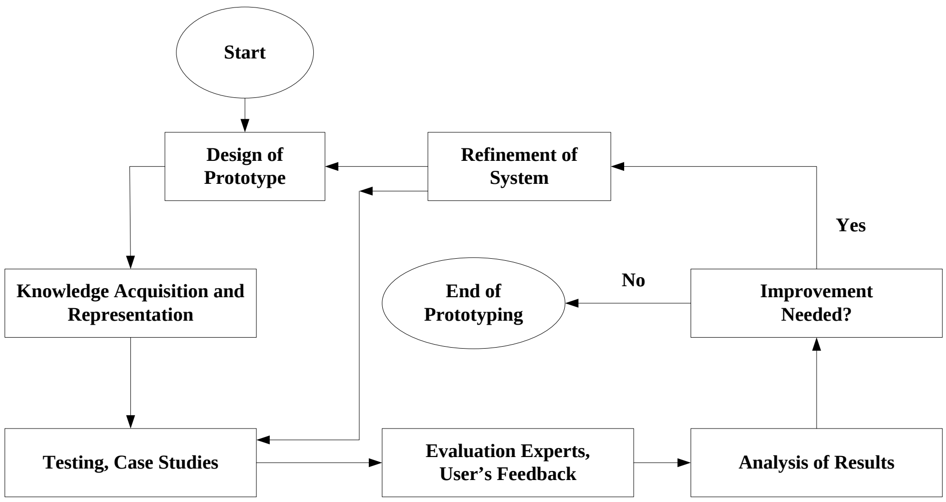

Figure 1 Rapid Prototyping Process (source: [29]).

The process of developing the prototype system started with the selection of the software for integrating materials management and resource modelling in order to create the development environment, design the system architecture, and identify the software and hardware integration requirements. Next, several tests were carried out in order to examine all the functions that the developed prototype system could operate appropriately based on the program code and detection with RFID tags. Afterwards, project managers and site managers were invited to participate in an evaluation session to gain feedback from professionals regarding the effectiveness of the software. Refinement of the prototype system was based on analysis of the feedback obtained from the professionals involved in the evaluation.

4 System Development Tools

The tools selected for the development of the materials tracking system included a laptop, and RFID system (tags and reader). Automated data collection using RFID for tracking materials involves the use of a tag (as a transponder) and a reader (as an interrogator). The RFID equipment included active RFID tags with a range of 100 metres/300 feet (read/write range), with adjustable output power for a read/write range that was tunable up to 100 metres/300 feet from the RFID reader (interrogator). The tags were selected based on a large memory capacity, making them suitable for use in all the proposed processes. All the tools used for the prototype system are shown in Figure 2. The integration of RFID-based materials management and resource modelling is required to amalgamate all of the selected software. This entails integrating a database system (such as Microsoft ® Office Access) as an intermediate application, Microsoft ® Office Project for resource modelling, with Microsoft ® Visual Basic.Net as the programming language to develop the prototype system.

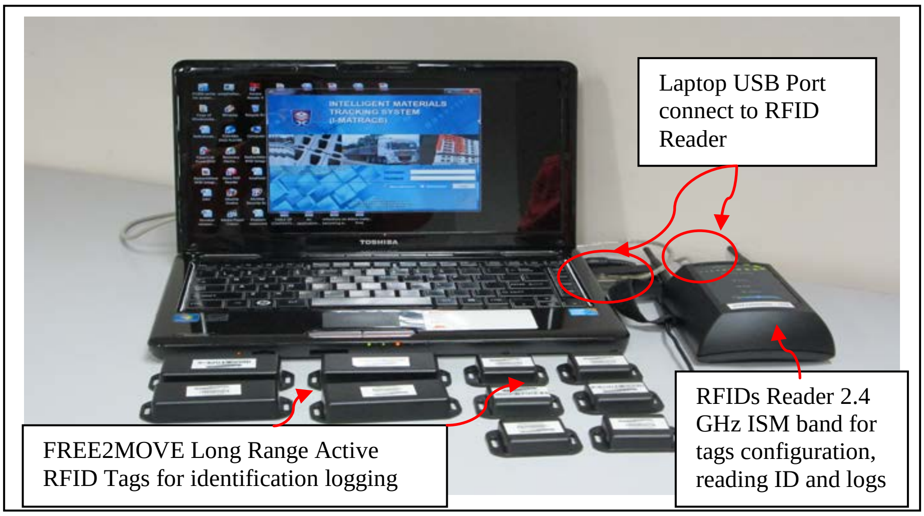

Figure 2 Hardware for Materials Tracking System.

5 Intelligent Materials Tracking System

The Intelligent Materials Tracking System (I-MATRACS) was designed to automate previously labour-intensive and error-prone transactions. Automated data collection using RFID for tracking materials involves the use of a tag (as a transponder) and a reader (as an interrogator). The system can be divided into three main components, i.e. automated materials tracking (using RFID), central database (Microsoft ® Office Access) and resource modelling (Microsoft ® Office Project). Each component plays a different role in the system. The RFID equipment enables the automated materials tracking while the central Microsoft ® Office Access database provides the information on delivery status, and Microsoft ® Office Project provides planning and scheduling of the project activities. The Intelligent Materials Tracking System has three main graphical user interfaces:

- Intelligent Materials Tracking System (I-MATRACS);
- Materials Registration;
- Materials Delivery Status.

When the system is started, the main screen is displayed (refer Figure 3). It shows the forms for "Intelligent Materials Tracking System (I-MATRACS)" and displays the "Login" button. The "Login" button provides a gateway to other forms in the application after users of this application have entered their username and password. The users of this application can be divided into two categories, i.e. manufacturers and contractors.

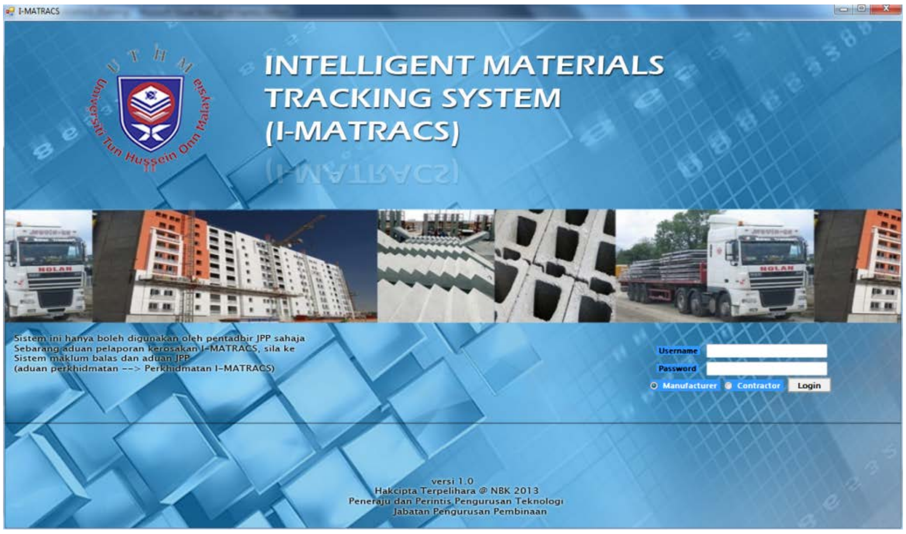

Figure 3 I-MATRACS User Main Screen

After clicking the “Login” button, a user of the first category (manufacturer) is redirected to the “Materials Registration” form as shown in **Figure 4**. This form enables the user (manufacturer) to register construction materials for specific projects by clicking the “Id Tag” menu item. The “Register Tag” form will appear to register new materials with attached by RFID tags. The user can stop this operation by closing the form, finalizing materials registration at the manufacturing site before the materials are delivered to the specific construction site.

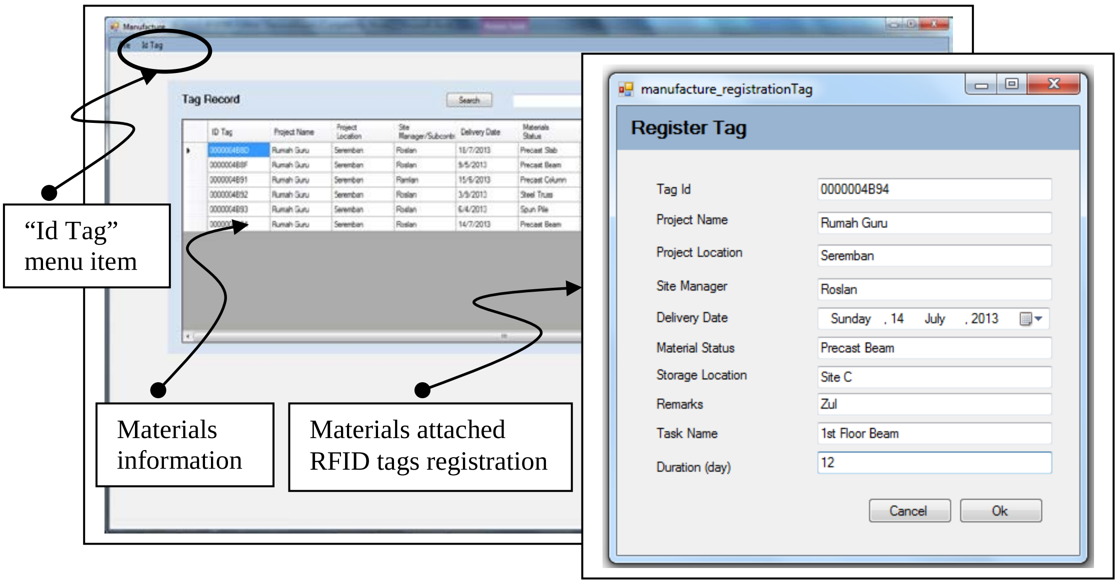

Figure 4 Manufacturer – Materials Registration and Information.

At the construction site, after clicking the “Login” button on the main screen, a user of the second category (contractor) is redirected to the “Materials Delivery Status” form as shown in Figure 5. The form displays the material status together with the RFID tag information (ID number). The system operates when the trucks carrying one or other material to be tracked are outfitted with rewritable RFID tags. RFID readers are installed in the loading areas. As the truck is loaded, information such as date, time, product, loader number, and site location is automatically written to the memory of the RFID tag by a reader in the loading area. This information is automatically sent to the staff’s system, which eliminates the time and errors associated with paper-based forms and manual entry. Reporting is automated and provides instantaneous tracking of productivity by the driver, date range, or site.

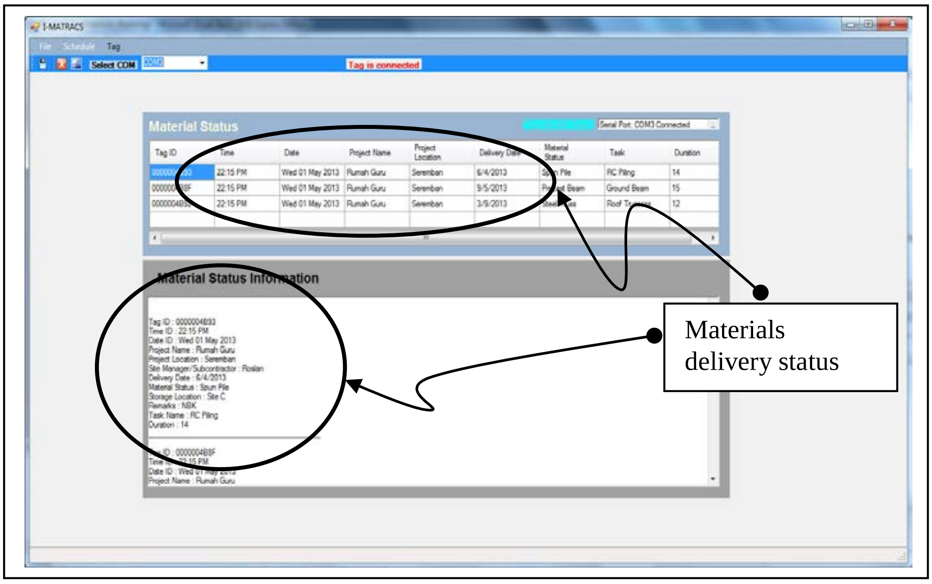

Figure 5 Contractor – Materials Delivery Status at Construction Site.

Figure 6 highlights the "Schedule" button, which provides a link to the work project programme in the MS Project application. This allows the user (contractor) to check and manage the materials tagged with RFID tags for related project activities.

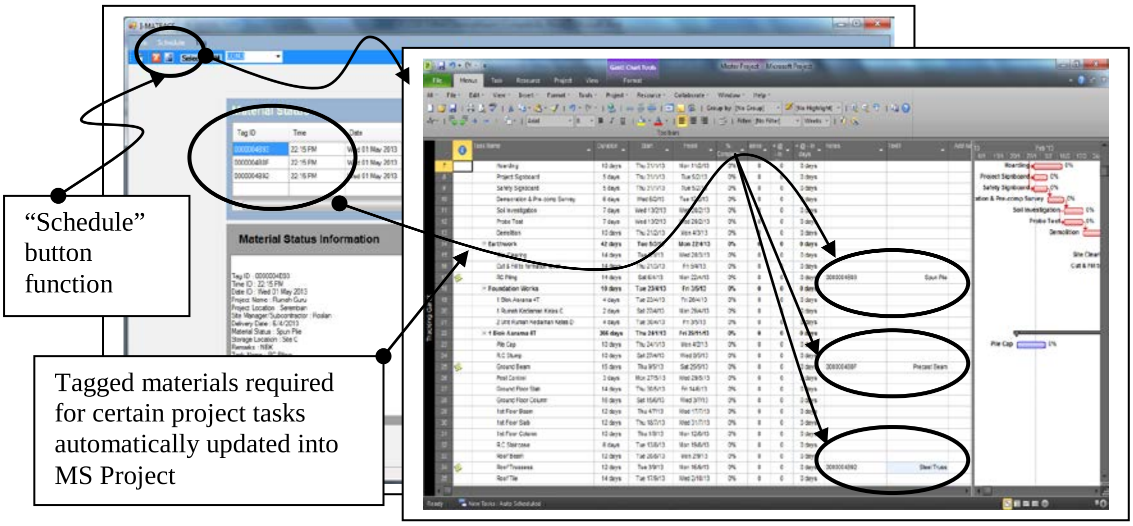

Figure 6 Contractor – Materials Information Recorded at MS Project.

6 System Testing

Testing is required to examine the complete prototype system before it can be evaluated by end users. According to [29], system testing is needed to test the functioning of a prototype system as a whole in order to determine if discrete modules will function together as planned. The testing process tries to verify the whole system's functionality and checks whether discrepancies exist between the way the system actually works and the way it was conceived. There are two stages of system testing, i.e. pre-design testing and post-design testing [31]. Pre-design testing (when no coding exists yet) happens during the design stage, where a paper-based system was designed to review the specifications or design document aimed at developing a feasible real-time materials tracking system for construction projects.

At the stage called post-design testing, after coding has started, "coding walkthroughs" are used to review the program code by computer test runs. Throughout this stage, the debugging process is undertaken for discovering and eliminating errors and defects (bugs) in the program code. The debugging process is repeated until all discovered errors are eradicated from the code. The process of building a prototype system, testing it out, refining it, and trying again and again is an iterative process of system development because the steps required to build the system are repeated over and over again.

Several tests were carried out by the researcher (self-testing) in order to examine all the functions of the developed prototype system so that it could operate appropriately. After undertaking many debugging tests that showed that the system was running successfully, the final task of the prototype system testing involved self-evaluation by the researcher using several data sets. This was done to examine the appropriate way of handling the RFID tags and readers and the interaction with the prototype system. This involved varying the positioning of the RFID tags on the sample materials and scanning/pinging them from different distances and angles. The user can easily choose the data provided by the prototype system in order to test if the system is working appropriately. After the process of prototype testing was done it could be concluded that generally the system features were working appropriately to satisfy the main objective of the integration of the materials tracking and resource modelling system to improve materials management in construction projects.

7 Conclusion

First, the requirements towards a materials tracking system have been discussed. Next, the choice of the hardware and software for the system development tools of the prototype system was discussed. This paper also presented the operation of the prototype system, which consists of an intelligent materials tracking system, materials registration and material delivery status. Based on the findings from the system testing, the prototype system generally works appropriately. Further testing of the prototype system on real materials tracking situations on sites of various types of construction projects is considered necessary. The results from these can further demonstrate the system's applicability in different materials tracking problem scenarios.

Acknowledgements

The author would like to thank the Office of Research, Innovation, Commercialization and Consultancy (ORICC), UTHM, for supporting this research.

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