IoT-Based Architecture to Improve Workflow in Bricks Manufacturing

Dorra KARMAOUI[1*], Wassim AL BALKHY[1], Thomas DANEL[2], Agnès JULLIEN[3], Zoubeir LAFHAJ[4], Christophe CHAPISEAU[5]

[1] *Doctoral Candidate, Centrale Lille, CNRS, LaMcube, Lille, France*
[2] *Postdoctoral Researcher, Centrale Lille, CNRS, LaMcube, Lille, France*
[3] *Doctor HDR, Laboratoire AME-EASE, Univ Gustave Eiffel, IFSTTAR, Bouguenais, France*
[2] *Full Professor, Centrale Lille, CNRS, LaMcube, Lille, France*
[4] *Factory Director, Briqueteries du Nord (BDN), Lille, France*
[*] *Corresponding author's e-mail: dorra.karmaoui@centralelille.fr*

ABSTRACT
For thousands of years, bricks have been considered one of the most important and indispensable materials for most construction projects. Nevertheless, brick manufacturing is mainly composed of small and medium-sized enterprises (SMEs) that still need to make greater efforts to adopt automation and digitized solutions to face the difficulties that face the industry and create improvements related to efficiency, quality, and waste and cost reduction. This article proposes an internet of things (IoT)-based platform to improve workflow in bricks production. The platform aims to detect the number of stoppages in the production process, report these stoppages, and identify the sources of variability and inconsistency in the workflow. The article explains the development of the platform and its different components, its use in a family SME in the north of France, and the faced challenges during the use of this platform.

KEYWORDS
Bricks, Bricks manufacturing, industry 4.0, Internet of things (IoT), sensors, workflow, offsite construction.

INTRODUCTION
The tremendous population growth, migration of people to urban areas, unreliable supply chain due to the impact of the last pandemic of COVID-19, and the crises around the globe are among the factors that are creating a huge gap between demand and supply of affordable shelters and homes for people and calling the need to make changes in the construction systems. These changes, for example, but not limited, include improving the way of constructing the buildings and moving toward modularity and offsite construction to cope with the quick and unexpected events, changing the managerial concepts, and adopting more efficient philosophies (e.g. lean, agile…etc.), moving toward automation and digitization and adopting new technologies to benefit from their impact on projects measures (e.g. cost, quality time, collaboration, sustainable indicators…etc.), and improving the ways of preparing construction materials and components.
Among the construction materials, brick is one of the oldest, most irreplaceable, and most popular ones as its use goes back thousands of years and until today, the demand for bricks is very high

and expected to increase due to the need to secure housing for the growing number of people (Shakir et al., 2013; Singh et al., 2021).

Bricks manufacturing is a small-scale-based industry as the majority of actors in this industry are small and medium-sized enterprises (SMEs) (Gomes & Hossain, 2003; Kumar et al., 2021). Accordingly, despite the flexibility SMEs can create in this sector, brick manufacturing faces several difficulties due to increased competition, low efficiency, lack of adequate funding, lack of skills, high levels of production waste, poor operational performance, and poor productivity and efficiency (Arevalo-Barrera et al., 2019; Chavez et al., 2019; Utami Handayani et al., 2020). According to Aka et al (2020), bricks production processes are characterized by high levels of non-value adding activities that are poorly monitored and significantly influence the production cost, quality, and duration.

To overcome these problems, industry 4.0 proposes different solutions that can provide improvements in productivity, efficiency, cost-saving, and time reduction to enable SMEs to innovate and enter global markets (Dutta et al., 2020; Grube et al., 2017). Among these solutions, the Internet of things (IoT) has the potential to manage production processes efficiently and effectively by providing opportunities to collect real-time data and feed them into the organizational decision-making structure for processes monitoring, control, and optimization and for energy consumption, proactive maintenance, and supply chain management (Caputo et al., 2016; Yang et al., 2016). IoT is also helpful to improve green manufacturing as it helps to monitor air pollution in plants, detect waste in energy, support green and reverse logistics operations, monitor supply chain and emissions from transportation and utilization of materials (Munson Pacis et al., 2017; Xu et al., 2012). Additionally, IoT can be integrated with lean to improve the detection and elimination of non-value-adding activities (Aydos & Ferreira, 2016; Balaji et al., 2020; Zhang et al., 2019). This article aims to show an example of the applicability of IoT platforms in process management in bricks manufacturing by presenting a case study from a bricks factory in France and reporting the results of this case. The article has four main sections; 1) the introduction; 2) the research methodology, which presents a description of the location of the study and a description of the platform and its components; 3) Results, which reports the implementation phase of the platform and the observations during this phase; 4) Conclusions, which shows the overall conclusion, limitations, and directions for future research.

RESEARCH METHODOLOGY

Case Description

This study was conducted in a brick manufactory company based in the north of France. The company has mainly four types of activities, which are brickworks, inert materials fill, a recycling center, and a materials trading site. Brickworks in the company started more than 100 years ago and include producing clay bricks (solid bricks, perforated bricks, and clay brick plates). The company is a bricks provider for many construction sites and projects in France, England, Ireland, and many other locations. Nevertheless, the company has faced several challenges in the last few years; for instance, high levels of waste (waiting times due to high preparation and adjustment times, high breakdown times, low machinery performance, and repetition of activities due to equipment failure), high competition, and shortages in the skills that affect the ability to respond to the demand by customers. Additionally, due to the recent pandemic of COVID-19 and the impact of the Brexit, the pressure became higher as the company has to respond to the rising need for local innovativeness and higher productivity due to the challenges facing the local and global supply chain and the increasing prices in the materials. Consequently, the company started a series of automation and quality improvement actions to respond to these challenges and eliminate the waste in the production processes, and improving the value provided to the customers. The current case reports one of these actions, which is mainly developed to prevent stoppages in the workflow of the activities and reduce the waiting time in the chain.

IoT System Development

The process of brick manufacturing in the studied case can be divided into different phases as shown in Figure 1, including the extraction of raw materials (clay), preparation of the clay to be used in the production (grinding and mixing, and dosage mixing), shaping of the bricks, drying, firing and cooling, and packaging the final products before shipping them to the customer.

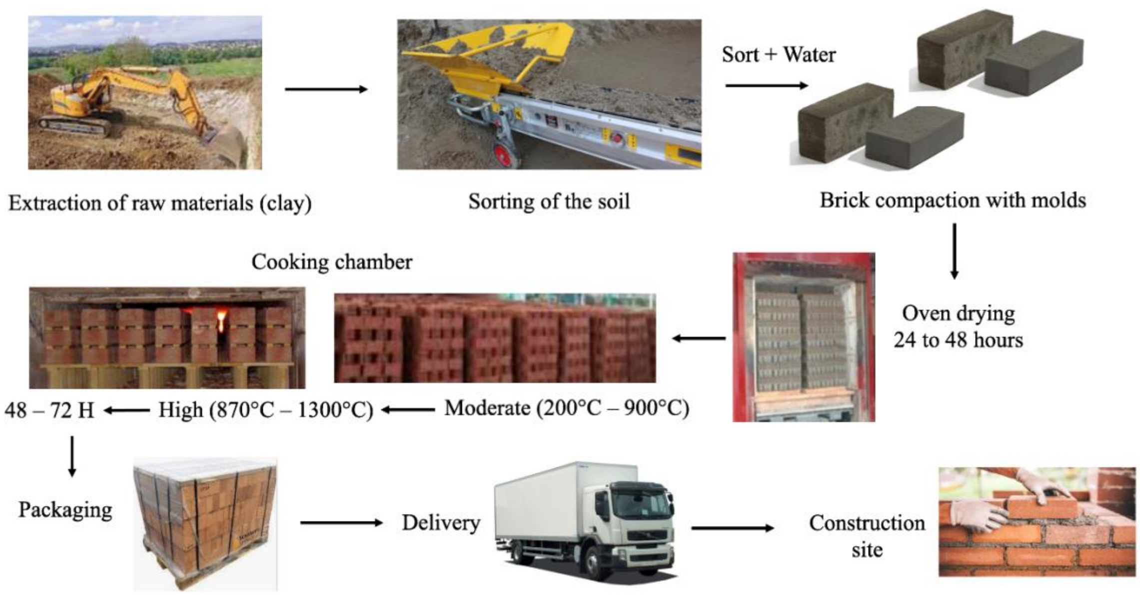

Figure 1. Bricks manufacturing process

Based on local observations made in the company, many stoppages were noticed between the cooling and packaging stages. Between these two phases, bricks that are cooled after they were taken from the kiln move on a conveyor, where a quality control stage is done by two workers who work to ensure that the final product meets the quality standards and does not have any stain, crack, or damage. The bricks that feel to meet the quality standards are put in a dumpster to be recycled again. Two robots are also found in this area; the first one is responsible for grouping the bricks in uniform rows after the quality control and before being sent to the other robot that is responsible for putting the bricks on pallets before packaging them to be sent to the customer or the storage areas.

Due to these stoppages in this area, the whole production line was affected and the production time was increased very frequently. Accordingly, there was a need to identify the number of waste in the production line that affect the flow of the activities in the production process (i.e. stoppages in production), and the root causes for these wastes. To do so, an IoT platform was used. This platform was based on the following layers (as shown in Figure 2; Figure 2-a shows the different layers of the IoT platform, while Figure 2-b shows the flow of the data in the developed platform):

- Perception layer (sensors layer): sensors that capture the movement of the bricks were attached to the first robot to calculate the needed time to close the two sides of the grouping robot (every grouping activity is an event). Based on data collected earlier about the normal time for the events, it was decided that the shortest cycle time is (15 seconds) and that is when having no defects in the production; and the maximum normal time for the cycle when having defects is (180 seconds). Accordingly, it was decided to consider any event that takes more than 180 seconds as a stoppage or slowdown in the process. The location of the sensors is shown in Figure 3.

(a). IoT platform layers (b). Flow of data within the platform

Figure 2. IoT system development

- Network layer: the collected data from the sensors about the running time of the grouping machine is sent via Bluetooth Low Energy to a tablet that is fixed close to the conveyor to make it reachable by the operators in the same area. The tablet is accessed via users' accounts and passwords to ensure the security of the data. The interface in the tablet shows the time and duration of events and an option to allow the operator to add the reason for any slowdown or stoppage in the production. In turn, the table is connected to an online server via Wi-Fi in the secure protocol (SSL). The tablet and its interface are shown in Figure 4.
- Application layer: The online server that is connected to the tablet is responsible for saving, analyzing, and visualizing the data. The application layer also includes a mobile application that is connected to the online server. The system is connected also to the mobile phone of the manager and it allows him to be alerted by a notification every time the chain is stopped. The results of the data analysis include information about product counting, performance assessment, and reasons for having unreliable workflow. Particularly, product counting was based on calculating the number of grouped products that are sent for packaging after the end of the quality control phase. The interface provides the total number of products per hour, day, or week based on multiplying the number of bricks in each group by the number of grouping events (every closer of the two sides of the grouping machine)

Figure 3. The location of the sensors

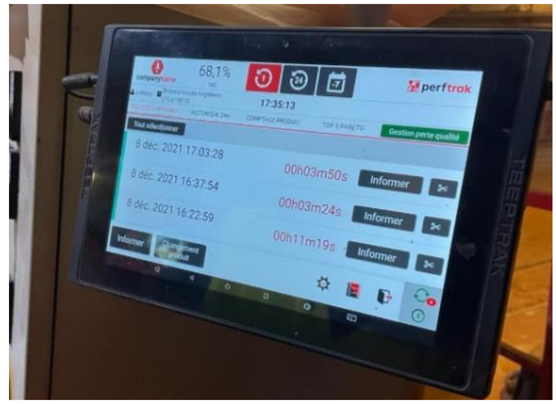

Figure 4. The used tablet and its interface

The system is also able to identify the percentage of defects, which is the total number of produced bricks minus the number of grouped bricks that are prepared for packaging.
In turn, performance assessment was based on the ratio of the real number of the produced bricks per a specific duration to the expected number of bricks in the same duration using the normal cycle time (180s).
Finally, to detect the most affecting factors on the flow of the produced bricks in the studied area, a list of expected reasons was developed and the operators in the area were asked to select the factor for every stoppage or slowdown in the process using the tablet. The list includes several factors including factors related to the operability of the machines (robots, or conveyors), or other factors related to the nature of the workplace or phase of the process (e.g. cleaning time of the workplace, the need for maintenances work, delays in the previous phases, preparation of the work area…etc.).
Figure 5 shows the results that appear on the interface after analyzing the data that are related to the counting and performance assessment.

Figure 5. IoT Platform interface- Performance assessment and product counting.

In turn, Figure 6 shows an example of the most affecting factors on the workflow in December 2021. The interface allows the users to export these results and link them with email.

Figure 6. IoT Platform interface- Factors affecting workflow

IMPLEMENTATION AND RESULTS

The system was implemented in February 2021. Since then, the system was helpful to identify the counting of final products and the performance of the production line. Accordingly, the data gathered from the system is helpful to identify the levels of defects in the production line. Nevertheless, since starting the implementation of the system, the identification of the reasons for stoppages or slowdown has witnessed some changes that have been made to improve the implementation of the system. In the beginning, the allocated time for each cycle was 15 seconds, following that the system was supposed to send alerts of stoppages or slowdowns in the flow of the activities. Nevertheless, at that time, it was noticed that the system was issuing alerts without having a real problem. It turned out that a change should be made to the cycle time to be more realistic (180 seconds). Additionally, the list of reasons behind the stoppages and slowdowns was also modified, re-categorized and simplified. This is because workers mentioned that the list was too long to be followed and that the reporting of the stoppage reasons during the work is difficult and time-consuming, so they requested to modify it to be easier to follow on time.

The implementation of the system showed that some of the reasons behind the stoppages in the production line are recurring very frequently. One of the most repeated problems is that during the quality control and when the defective bricks are thrown into the dumpster, some bricks may fall into the chain, which blocks the wagons from moving forward. Additionally, it was noticed that bricks sometimes fall from the kiln and pile up on top of each other's, which requires at least 2 hours to put them back in place. In addition to problems that happen in the palletization area and grouping robot, and those related to wagon preparation and blocking and packaging roll. Accordingly, recommendations to make improvements in these areas were delivered. Examples of the recommendations include for instance providing continuous maintenance for the machines, continuous monitoring to prevent fallen bricks in the chain that affect the movement of the wagon, and providing a transition system between the kiln and chain to prevent the piling of the bricks.

The implementation of the system was faced with some difficulties that are mainly related to the human and technical aspects. For instance, the use of the tablet remains, until now, a little difficult for some workers who find it difficult to deal with the problem in progress and to inform it on the tablet, which prevents the management from being in touch with the instant reporting of the problems. Additionally, the reporting of the reasons was affected by the feeling of accountability by the workers. Also, once there is a problem with the internet network the data and alerts cannot be retrieved instantly.

CONCLUSIONS

This study presents a conceptual framework for the use of IoT systems in improving the flow of activities in the bricks production line. This study aims to present a practical example and contribute to the existing knowledge and literature about the applicability of industry 4.0 practices in construction materials production. The use of IoT can be helpful to conduct real-time monitoring of the production systems and obtain instant data about the state of the processes. Accordingly, this data can be helpful to optimize the processes, identifying the risks, and mitigating their effect. The article also reports some of the difficulties that may face the implementation of IoT systems in brick manufacturing. Among these practices, the human factor seems to be the most apparent. Therefore, the inclusion of workers in the different phases of the IoT implementation is essential.
This work is built over a case study and due to the lack of continuity in the data due to the changes in the system, this article was based on reporting the composition of the system and the observations found during the implementation. Future studies can use a larger and more connected dataset to present advanced statistical analyses (e.g. regression models and time series) to identify the exact impact of IoT systems on the performance in brick manufacturing. Additionally, future work can cover the integration of other concepts and methodologies with IoT systems such as the integration between lean practices and IoT, or the use of the developed platform to build a digital twin system.

ACKNOWLEDGMENTS

This article reports a collaborative work between Centrale Lille and Briqueteries Du Nord. We thank TeepTrak for providing their innovation and technical expertise to support the implementation of the system and its use.

REFERENCES

Aka, A., Isah, A. D., Eze, C. J., & Timileyin, O. (2020). Application of lean manufacturing tools and techniques for waste reduction in Nigerian bricks production process. *Engineering, Construction and Architectural Management*, *27*(3), 658–679. https://doi.org/10.1108/ECAM-09-2018-0375/FULL/PDF

Arevalo-Barrera, B. C., Parreno-Marcos, F. E., Quiroz-Flores, J. C., & Alvarez-Merino, J. C. (2019). Waste Reduction Using Lean Manufacturing Tools: A Case in the Manufacturing of Bricks. *IEEE International Conference on Industrial Engineering and Engineering Management*, *December*, 1285–1289. https://doi.org/10.1109/IEEM44572.2019.8978508

Aydos, T. F., & Ferreira, J. C. E. (2016). RFID-based system for Lean Manufacturing in the context of Internet of Things. *IEEE International Conference on Automation Science and Engineering*, *2016-Novem*, 1140–1145. https://doi.org/10.1109/COASE.2016.7743533

Balaji, V., Venkumar, P., Sabitha, M. S., & Amuthaguka, D. (2020). DVSMS : dynamic value stream mapping solution by applying IIoT. *Sādhanā, 0123456789*. https://doi.org/10.1007/s12046-019-1251-5

Caputo, A., Marzi, G., & Pellegrini, M. M. (2016). The Internet of Things in manufacturing innovation processes: Development and application of a conceptual framework. *Business*

Process Management Journal, *22*(2), 383–402. https://doi.org/10.1108/BPMJ-05-2015-0072/FULL/PDF

Chavez, J., Osorio, F., Dominguez, F., & Raymundo, C. (2019). *Modelo esbelto de gestión de producción para la reducción de desperdicios en PYMES del sector alimentos procesados*. *August*, 40–52. https://doi.org/10.1007/978-3-030-20494-5

Dutta, G., Kumar, R., Sindhwani, R., & Singh, R. K. (2020). Digital transformation priorities of India's discrete manufacturing SMEs – a conceptual study in perspective of Industry 4.0. *Competitiveness Review*, 289–314. https://doi.org/10.1108/CR-03-2019-0031

Gomes, E., & Hossain, I. (2003). Transition from traditional brick manufacturing to more sustainable practices. *Energy for Sustainable Development*, *7*(2), 66–76. https://doi.org/10.1016/S0973-0826(08)60356-7

Grube, D., Malik, A. A., & Bilberg, A. (2017). Generic challenges and automation solutions in manufacturing SMEs. *Annals of DAAAM and Proceedings of the International DAAAM Symposium*, 1161–1169. https://doi.org/10.2507/28th.daaam.proceedings.161

Kumar, S., Sharma, P., Kumar, S., & Sharma, P. (2021). Adoption of cleaner production innovations by micro, small and medium enterprises: lessons from the clay-fired brick manufacturing sector in India. *International Journal of Management and Enterprise Development*, *20*(1), 49–74. https://doi.org/10.1504/IJMED.2021.113645

Munson Pacis, D., Jr Dela Cruz Subido, E., Bugtai, N. T., Mitch Pacis, D. M., & Subido, E. D. (2017). Research on the Application of Internet of Things (IoT) Technology Towards A Green Manufacturing Industry: A Literature Review. *DLSU Research Congress*. https://www.researchgate.net/publication/323258871

Shakir, A., Mohammed, A., Shakir, A. A., & Mohammed, A. A. (2013). Manufacturing of Bricks in the Past, in the Present and in the Future: A state of the Art. *International Journal of Advances in Applied Sciences*, *2*(3), 145–156. https://doi.org/10.11591/ijaas.v2i3.1751

Singh, H., Nazeer, M., & Kumar Tiwary, A. (2021). An Experimental Study of Bricks Made with Different Mineral Additives. *IOP Conference Series: Earth and Environmental Science*, *889*(1), 012049. https://doi.org/10.1088/1755-1315/889/1/012049

Utami Handayani, N., Agung Wibowo, M., Mustikasari, A., Wahyu Nurwidanto, I., & Akbar Dilaga, D. (2020). The implementation of lean construction and six sigma concepts in light brick installation: A case study in Cordova apartment project. *IOP Conference Series: Materials Science and Engineering*, *909*(1). https://doi.org/10.1088/1757-899X/909/1/012048

Xu, X., Jin, C., & Cao, Y. (2012). Smart Reverse Supply Chain: An Application of IoT to Green Manufacturing. *Applied Mechanics and Materials*, *141*(1), 493–497. https://doi.org/10.4028/WWW.SCIENTIFIC.NET/AMM.141.493

Yang, C., Shen, W., & Wang, X. (2016). Applications of Internet of Things in manufacturing. *Proceedings of the 2016 IEEE 20th International Conference on Computer Supported Cooperative Work in Design, CSCWD 2016*, 670–675. https://doi.org/10.1109/CSCWD.2016.7566069

Zhang, K., Qu, T., Zhou, D. J., Thurer, M., Liu, Y., Nie, D. X., Li, C. D., & Huang, G. Q. (2019). IoT-enabled dynamic lean control mechanism for typical production systems. *JOURNAL OF AMBIENT INTELLIGENCE AND HUMANIZED COMPUTING*, *10*(3), 1009–1023. https://doi.org/10.1007/s12652-018-1012-z