Smart Farming for Poultry: Leveraging Chicken Raising with Low-Cost IoT-based Information Systems

Carla Hanau
State University of Goiás
Posse, Goiás, Brazil
carlanebelle@gmail.com

Vinícius Lopes
University of Notre Dame
South Bend, Indiana, USA
vlopes@nd.edu

Mateus Santos
State University of Goiás
Posse, Goiás, Brazil
mateusdi.santosz@gmail.com

Roberto Oliveira
State University of Goiás
Posse, Goiás, Brazil
roberto.oliveira@ueg.br

Valdemar V. Graciano-Neto
Federal University of Goiás
Goiânia, Goiás, Brazil
valdemarneto@ufg.br

Mohamad Kassab
Penn State University
Malvern, Pennsylvania, USA
mkassab@ieee.org

José Maria N. David
Federal University of Juiz de Fora
Juiz de Fora, Minas Gerais, Brazil
jose.david@ufjf.br

Regina Braga
Federal University of Juiz de Fora
Juiz de Fora, Minas Gerais, Brazil
regina.braga@ufjf.br

Abstract

Context: Brazil is among the most influential global poultry meat production countries. Occupying second place among the world's largest producers, Brazil is the first in the export ranking. Hence, to meet the high demand, the market depends on the high productivity and performance of the birds produced. ***Problem:*** As a tropical country, production faces difficulties due to the birds' sensitivity to fluctuations in environmental factors, such as temperature and relative humidity. These and other factors can lead to loss of production and low profitability. ***Proposed Solution:*** This paper investigates the impact of a low-cost IoT-based Information System (IS) for autonomous environmental regulation in poultry farming. ***Information Systems Theory:*** We conduct this research under the positivism umbrella, while still conceiving the solution under the General Systems Theory. ***Method:*** We conducted a classical controlled experiment. We used free-range chicken breed *Label Rouge* and *Gallus Domesticus*, separating them into intervention environment (under climate monitoring and regulation) and control environment (without monitoring/regulation). We considered the following variables for data analysis: weight gain, feed consumption and mortality. Student's t test was applied. ***Summary of Results:*** The results showed a significant gain in the Label Rouge free-range chickens breed in the fifth week of evaluation, with the monitored chickens obtaining an average weight of 25% greater than those not monitored. ***Contributions and Impact in the IS area:*** The contributions of this research can be considered twofold: prescriptive, with the proposal of a low-cost IoT-based IS architecture for autonomous environmental regulation in poultry farming; and descriptive, with an empirical study being conducted and the results being reported. We conclude that the system's automation can significantly reduce the need for manual monitoring, offering substantial labor savings and operational efficiency, especially advantageous for small-scale poultry producers.

CCS Concepts

• **Information systems**; • **Hardware**;

Keywords

Internet of Things, Precision Livestock Farming, Agribusiness

1 Introduction

Poultry farming is pivotal in global food security, with chicken consumption projected to surpass 140 million metric tons annually by 2024 (FAO, 2023)[1]. Brazil, as the second-largest producer and leading exporter of poultry meat, stands at the forefront of this industry. However, small-scale farmers contribute significantly to local production and face persistent challenges that threaten their livelihoods. In tropical climates, fluctuations in temperature and humidity often lead to reduced poultry performance, increased mortality, and diminished profitability [7], [8].

Technological advancements, particularly in Internet of Things (IoT) systems, have transformed large-scale farming by enabling precise environmental monitoring and control [17], [10]. Despite these successes, such systems still need to be more affordable for small and medium-sized producers who rely on manual monitoring. This gap highlights the urgent need for accessible, low-cost technologies tailored to small-scale operations.

This paper is part of a broader research effort that proposed and developed a low-cost IoT-based information system for autonomous environmental regulation in poultry farming. An overview of the system has been presented in our previous work [12]. By integrating sensors, automated climate control mechanisms, and real-time monitoring features, the system aims to enhance poultry welfare and productivity while reducing labor demands. To assess its effectiveness, a mixed-methods empirical study was conducted, incorporating both qualitative and quantitative approaches. Quantitatively, an *in situ* controlled experiment was conducted over a one-month period by a software engineer and an agronomist, focusing on the *initial phase of poultry feeding and fattening*. This phase included a comparative analysis of the weights of poultry raised with and without the system, alongside benchmarking these results against

[1]https://www.fao.org/markets-and-trade/commodities-overview/basic-foods/meat/en

established industry standards [1]. This paper presents the findings from the evaluation phase of the proposed system.

The remainder of this paper is structured as follows. We introduce the design of our mixed-methods empirical study, including the study goal, research questions, and study steps. After, we present the interview study results, and the controlled experiment results. Finally, we conclude this paper and suggest future work.

2 Information System Architecture Overview

The proposed IoT-based information system was developed to address the environmental challenges faced in poultry farming by enabling autonomous monitoring and regulation of critical variables such as temperature and humidity. Humidity levels and temperature are crucial for bird health and development. High humidity can cause respiratory weakness, compromising weight. In general, temperature control is inefficient in cases of humidity imbalance, since the bird will continue to have the same symptoms of heat stress. Therefore, the ideal temperature should be between 30° and 34°C and relative humidity between 50 and 70%.

The architecture integrates modular components that ensure cost efficiency, ease of deployment, and operational resilience, making it particularly suitable for small-scale poultry producers [12].

At the system's core are monitoring devices equipped with sensors, including SHT20 for temperature and humidity measurement, which continuously collect environmental data. These devices are supported by a dual power supply system—a direct current plug and a backup battery—to maintain uninterrupted operation during power outages. Data collected by the sensors are stored locally on an SD card and processed by the JARM ESP32 board, which runs the system's automation algorithms. This ensures that monitoring functions are not disrupted even if connectivity issues arise.

The gateway module acts as the bridge between the monitoring devices and the cloud-based platform. It includes a LoRa module for long-range communication, enabling data transmission to the gateway. We opted for LoRa technology due to the need for long-distance communication in a region with poor Wi-Fi connectivity. LoRa proved to be the ideal solution for covering areas without reliable internet access. The gateway further connects to the ThingSpeak cloud platform via Wi-Fi, where data are aggregated, processed, and visualized in real time through interactive dashboards. This library makes it easy to connect our IoT device to ThingSpeak, allowing us to send data for monitoring and analysis using the platform's API. The modular design of the architecture ensures that each component operates independently; for instance, environmental monitoring and data logging continue uninterrupted even if the gateway or cloud platform experiences downtime.

The algorithms, embedded within the ESP32 firmware, play a role in environmental regulation. Based on predefined thresholds for temperature and humidity, these algorithms (written in Arduino and C++), alongside a relay module, activate control mechanisms such as fans for cooling or heating lamps for temperature stabilization. This adaptive approach ensures optimal living conditions for poultry, minimizing environmental stress and enhancing productivity.

We chose a 5V, four-channel relay module, even though only two channels were used (for the fan and lamp). This module handles the automation by controlling the on/off states of the fan and light, sending signals to either block or allow power flow to these devices.

The system's architecture, which includes four monitoring devices and a gateway, costs around USD 250. Figure 1 illustrates the architecture, showcasing the seamless interaction between the monitoring devices, gateway, and cloud platform. This robust, low-cost design addresses the key challenges of poultry farming in tropical climates, where producers face a great variance of temperature that could kill chicks, providing small-scale farmers with an accessible tool for improving operational efficiency and poultry welfare.

3 Study Settings

This section details the research method structured into well-defined steps and the research protocol.

3.1 Protocol

The objective of this study is to evaluate the impact of a low-cost IoT-based Information System (IS) for autonomous environmental regulation in poultry farming. Using the Goal-Question-Metric template [4], we structured the study to achieve two aims: (i) assess how the system reduces the effort required by poultry producers, and (ii) evaluate its effectiveness in improving poultry production monitoring; *with respect to* i) the poultry producer's perception of effort put into handling the production over time and ii) the poultry weighting with and without using the system; *from the point of view of* i) a Brazilian small-scale poultry producer and ii) an agronomist currently working for an international company that provides crop inputs and services; *in the context of* producers who manage their farm mainly through their own and their family's labour, and a specific chicken livestock. We defined the following research four questions (RQs) to guide our study:

RQ1: *Does the IS improve the effectiveness of poultry handling compared to production without the system?*
Rationale: One of the most important criteria for choosing an IoT-based IS is its effectiveness. We consider an IoT-enhanced IS to be effective if the producer, using the system, obtains a greater weight in poultry handling than when s/he does not use the system. This issue is because *having chickens as heavy as possible benefits the production gains.* In order to address this research question, we analyzed quantitative data. Through RQ1, we aim to understand if the system usage promotes improvements in the well-being of free-range poultry, so that they achieve more efficient productivity gains in production. The following null and alternative hypotheses were formulated for this RQ:

- **H_0** The use of IS does not affect the effectiveness of poultry handling.
- **HA1.1** Producers using IS obtain a difference in the average Label Rouge chicken weight constraints than producers without the system.
- **HA1.2** Producers using the IS obtain a difference in the average *Gallus Domesticus* chicken weight constraints than producers not using the IS.

RQ2: *Has the IS supported an average weight increase over time followed by a decrease in the total feed consumption?*
Rationale: The expected result is an increase in productivity. Hence, by answering this RQ, we can certify whether this goal was achieved.

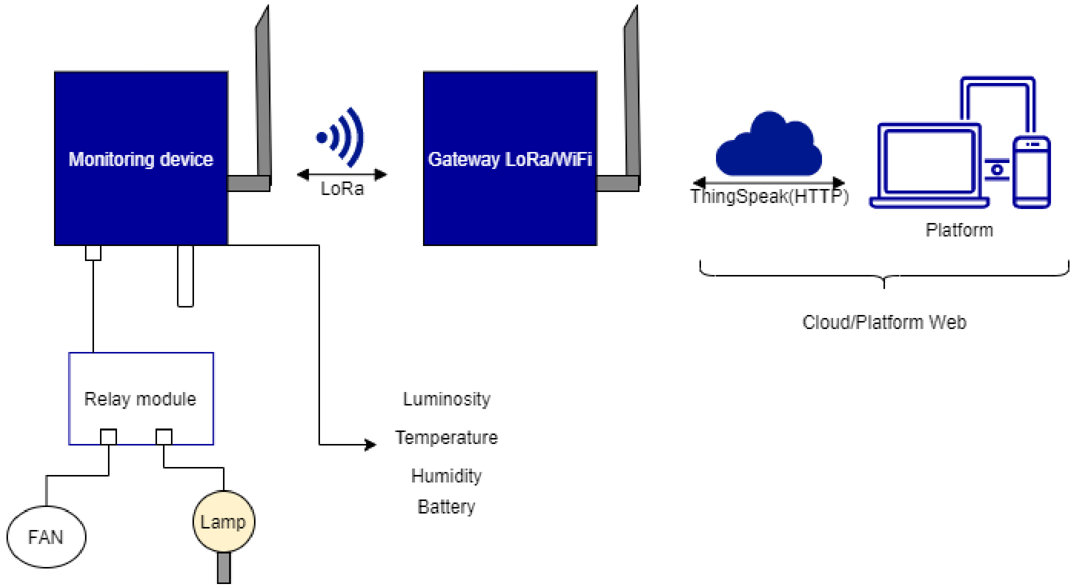


Figure 1: Overall Architecture of IoT-based IS.

RQ3: *Does the IS support the poultry handling in conformance with a well-established poultry weight benchmark?*
Rationale: By answering this RQ, we aim to compare the poultries raised in poultry houses under natural environmental conditions and those subjected to the thermal comfort parameters indicated in the literature. The goal was to identify if there are any differences in the development of the poultries under both conditions.

RQ4: *What is the perception of the producer regarding the use of the IS in poultry handling?*
Rationale: Collecting the perceptions of the producer is relevant for obtaining a qualitative perspective of the observed phenomena.

3.2 Scenario Description: Poultry Farm

After evaluating several options, we selected a poultry farm in the municipality of Iaciara-GO, situated at an altitude of 608 meters. The farm was chosen for its established experience in poultry production, diverse climatic conditions, and proximity to the producer.

The region has a tropical savanna climate (Aw, according to the Köppen classification), characterized by summer rainfall and cool, dry winters. Temperatures range from 18°C to 34°C on average. The property is 22 hectares in size, and its production is focused on cattle farming and free-range poultry production. The poultry is produced from the early stages of the bird's life until slaughter, with the chickens being raised in a semi-intensive system. In this rearing system, the chickens are kept in an isolated poultry houses. Until the 28th day of life, after which they have access to paddocks for a few hours daily, allowing them to graze.

3.3 Methods and Instruments

Our methodology follows established guidelines for conducting controlled experiments [18] and aligns with prior studies published in IS venues [6, 10, 14–16]. Qualitative research was employed to gain a deeper understanding of the benefits of IS deployment, incorporating insights directly from producers [11]. As performed by Horita et al. (2023) [10], we used semi-structured interviews to collect data to allow for insights by hearing the producers' perceptions. Analogously to other studies in IS venues and following Gregor and Hevner's Knowledge Contribution Framework [5, 9, 13], we aimed to provide a prescriptive contribution as the IS architecture artifact and descriptive contributions based on lessons learned from the experiment. The study consisted of seven steps.

Step 1: Design of the IoT-based Information System. We developed a prototype architecture capable of collecting environmental data, including temperature and humidity, using sensors, motors, and other IoT-based devices, as detailed in our previous work [12], in which we emphasized the differences of our system in relation to existing ones. In this current paper, we detail the study settings aiming at replication by other researchers.

Step 2: Application of questionnaire for species' characterization. A survey was conducted among poultry producers in the region to identify the most produced and sold bird species for the study's target area. Based on this, the Label Rouge breed was defined, also popularly known as the naked-neck chicken, due to its genetic characteristic of not having feathers in the neck area.

Step 3: Experiment planning. After defining the breeds, the project for the execution of the experiment was created using using AUTOCAD software. Through this planning, the dimensions of each stall area (1.90 x 1.65), the placement of monitoring equipment, the arrangement of the waterers and feeders, and heating lamps and fans were determined, as shown in Figure 2. After planning the stalls, the number of chickens to be analyzed in each treatment was determined, resulting in 10 chickens per stall, with a total of 20 chickens in the experiment.

Stpe 4: Stalls preparation. The stalls were assembled inside the property's poultry house, with the enclosure made of 1-inch-thick mesh (suitable for poultry houses), covered with tarpaulin to protect the chickens from strong wind currents and excessive cold.

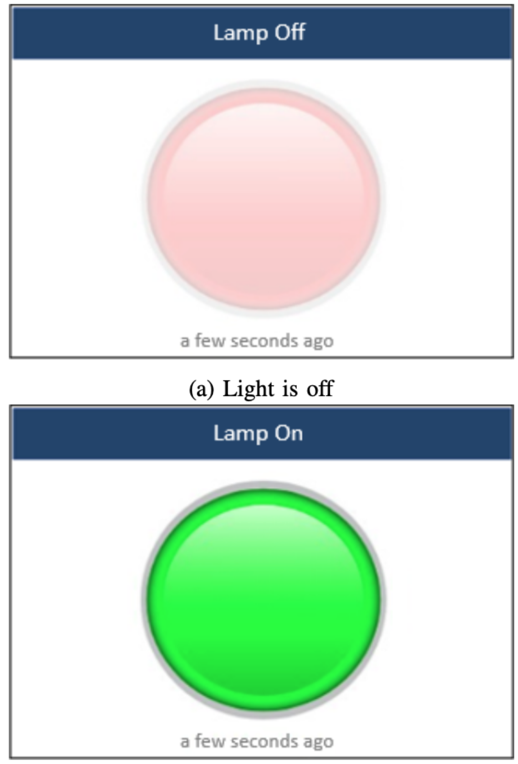
Step 5: Implementation of the experiment. The chicks were purchased from an agricultural supply store in the city of Iaciara-GO (Brazil). They were all one day in their lives and all properly vaccinated. The chickens arrived at the experiment site in good health, and as soon as they were placed in their stalls, they were shown where the water and feed were. Throughout the experiment, food and water were provided in abundance and in equal quantities, offered twice a day, in the early morning and late afternoon. The poultry bedding (material used to absorb moisture and retain manure and feathers), made of oak wood, was replaced every seven days. The same amount of bedding was deposited in the stall and distributed throughout the floor. During the change, the used bedding was collected and placed into plastic bags labeled with the collection date and the respective stall information.

The automated monitoring system was then activated and the heating lamps in all stalls were turned on, as shown in Figure 2. It is worth noting that each stall had one heating lamp in each enclosure, which remained continuously throughout the experiment. This issue is because in the early life phase of the chickens, they require an environment with an average temperature of 31°C for their thermal comfort. On the other hand, the stalls under monitoring had an additional heating lamp connected to the system, which was only activated in case of a temperature drop and when the environment was in thermal imbalance, as shown in Figure 3. Similarly, each of the monitored stalls also had a fan that, when activated by the system, was responsible for cooling the environment if the temperature rises above the ideal range for production.

Figure 2: Activation of heating lamps by the system

The experiment was subjected to two environmental conditions, each being used for each chicken species. Consequently, four stalls were segmented, with two stalls subjected to the automatic monitoring and climate control system, and the other two without the monitoring system. All the chickens were labeled and identified for the accurate collection of data, especially regarding the weight gain of the chickens.

During the data collection period, the researchers monitored and supported the proper functioning of the hardware and software components. In addition, they trained the employees responsible for poultry management to equip them with the skills needed to use the software and properly handle the hardware equipment.



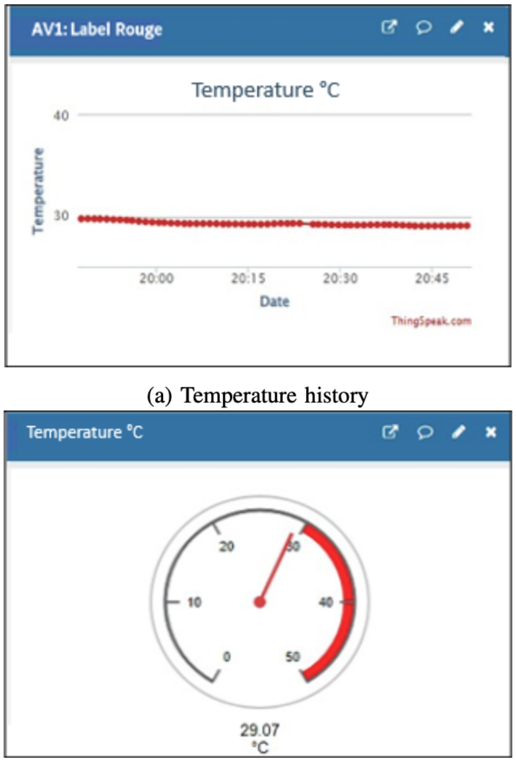
(a) Light is off

(b) Light is on

Figure 3: Heater lamp activation status provided by the IoT Information System

The monitoring system tracked temperature variations, as shown in Figure 4(a), for example, and humidity throughout the data collection period. Based on this data, whenever there was a deviation from the pre-established patterns of these variables, the system would activate the appropriate control method through an alert (fan for high temperatures and heating lamp for low temperatures) in order to restore balance to the environment. The producer had full access to the IS interface during the experiment and monitored daily temperature averages and aviary humidity. He also had access to easily visible real-time interactive dashboards, as shown in Figure 4(b). Additionally, through this software system, the producer could monitor the status of the environmental control resources, whether they were active or not, such as the extra heating lamp and the fans for cooling the poultry house.

Step 6: Poultry handling. As handling routine for the non-monitored chickens, observations were conducted approximately four to six times a day, to observe their behavior and identify possible thermal and environmental discomfort. Monitoring was carried out via an application for the monitored chickens, providing real-time information on the chickens' environment throughout the day. When the environment became unbalanced, the system automatically activated the control mechanisms, and the producer



(a) Temperature history

(b) Real-time temperature

Figure 4: Temperature information provided by the IS.

did not need to visit the location physically. As for the bird feed, a composition with the appropriate nutrient levels was accordingly purchased to support the early life stage of the chickens. On the other hand, the water came from an artesian well belonging to the property, ensuring purity and quality suitable for the chickens.

Step 7: Semi-structured Interview. In addition to the quantitative analysis, we interviewed a small-scale Brazilian poultry producer. Our primary goal was to understand how much the IoT information system reduces the effort spent by poultry producers.

In order to conduct the interview process, the first step was to schedule a meeting with the producer. The first contact with the producer was through a text chat on a cell phone. In this call, we introduce the interview context, the estimated duration (twenty minutes) and your availability to schedule the interview.

The interview happened on October 4th, 2022 through audio and video meetings using Google Meet. Before the interview, a consent form was elaborated and applied to the participant to agree with the interviews to be recorded. The interview began with an explanation of the context the questionnaire and a justification, in which the participant understood the types of questions that would be asked. The interview lasted thirty minutes, slightly exceeding the estimated time, but it was fine since the participant did not complain.

3.4 Data collection

Data collection spanned the first 28 days of the chickens' lives, with measurements taken at 1, 7, 14, 21, and 28-day intervals. Each chicken was individually weighed using a precision scale, and the results were recorded in an electronic spreadsheet. Alongside the chickens, the amount of feed provided during the week was weighed, and the bedding was changed with the collection of residues that were subsequently evaluated.

During data collection, researchers visually monitored the chickens for signs of mortality and symptoms of diseases. Simultaneously, the automated monitoring system was examined to identify possible potential maintenance needs and carry them out if necessary.

For the collection of wasted feed, the weighing was done with 100% of the collected bedding contents. Subsequently, they underwent a sieving process, which initially involved passing through a 4mm sieve and then through a 2mm sieve. At the end of this process, the separated feed from the bedding was weighed again to determine the waste index for the week.

3.5 Data tabulation

For data analysis, the variables considered included **(i) bird weight gain, (ii) feed consumption, and (iii) bird mortality**. Collected weight data were analyzed to track weekly weight gain progression, and batch averages were calculated for each time interval. Following this principle, to assess feed consumption in addition to the weight of feed provided, the wasted feed found in the bedding was collected. By subtracting the values of the wasted feed from the provided feed, it was possible to identify the actual feed consumption values.

After a preliminary data analysis, it was decided to apply the parametric Student's t-test to test the hypothesis regarding the difference between the control and the intervention (unmonitored vs. monitored) on animal weight. Therefore, the t-test was applied to compare the average weight of the animal samples of each species evaluated for each week of data collection.

Finally, the evaluation results were presented through boxplots with the respective distributions identified, which were then submitted to the Grubbs test, which aims to identify the presence of outliers (data points outside the curve or the dataset) in the sample. No outliers were identified in the sample, demonstrating uniformity in the data presented.

4 Results and Analysis

In this section, we report the results achieved in our study.

4.1 Experiment Results (RQ1 to RQ3)

4.1.1 Weight distribution analysis of Label Rouge and Gallus domesticus chickens (RQ1). We analyzed the weekly weight gain of chickens, comparing those monitored by the automated system to those in the unmonitored control group. We then investigated whether the monitored chickens showed differences in weight gain compared to the non-monitored ones, specifically evaluating if the monitored group tended to achieve greater weight.

Thus, to perform the analysis, the average weight of the monitored and non-monitored chickens was calculated by adding up the individual bird weights and dividing this value by the total number of chickens. Consequently, we obtained the weekly weight averages for the monitored and non-monitored chickens, making it possible to initially investigate the alternative hypotheses as follows:

- **HA1.1** Producers using IoT information systems obtain a difference in the average Label Rouge chicken weight constraints than producers without IoT information systems.

Based on the statistical data analysis, Figure 5 presents the boxplots showing the distribution of the average weight of Label Rouge chickens monitored and non-monitored in the fifth week of the experiment. In the fifth week, monitored chickens had an average weight of 573.0g, compared to 424.5g in the unmonitored group. This issue shows that monitored chickens achieved an average weight 25% higher than their unmonitored counterparts. Applying the Mann-Whitney test, a significant difference was observed in the chickens' weight values (p-value = 0.045). This result leads us to reject the null hypothesis H_0 and accept the alternative hypothesis HA1.1 for Label Rouge breed samples throughout the entire observation period, the fifth week.

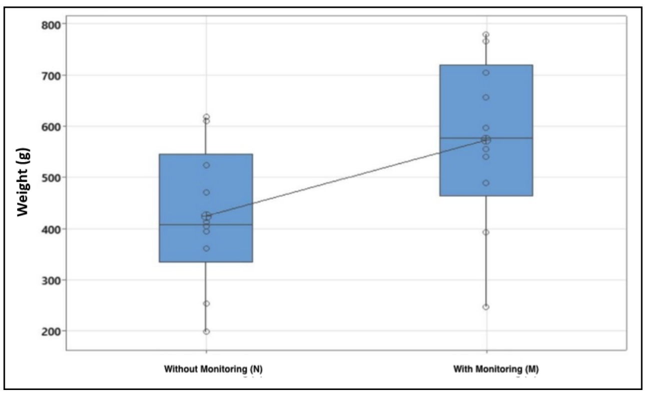


Figure 5: Weight distribution of without Monitoring and with Monitoring Label Rouge breeds (T-test for 5th week)

- **HA1.2** Producers using the IS obtain a difference in the average *Gallus Domesticus* chicken weight constraints than producers without the system.

On the other hand, after investigating the alternative hypothesis HA1.2, Figure 6 presents the boxplots showing the average weight distribution of *Gallus domesticus* chickens monitored and non-monitored in the third week of the experiment. In general, in that week, an average weight of 72.8 g was observed for the non-monitored chickens compared to 91.7g for the chickens subjected to the automated monitoring system. Thus, our results suggest that the monitored chickens achieved an average weight that is 20% higher than the non-monitored ones. Applying the Mann-Whitney test showed a significant difference in the chickens' weight values (p-value = 0.029). In summary, our results lead us to reject the null hypothesis Nh and accept the alternative hypothesis HA1.2.

We observed that *Gallus domesticus* chickens showed a significant experimental difference in average weight between those being monitored and those under natural environmental conditions. However, this difference was observed only in the third week of the experiment, and did not persist in the subsequent weeks.

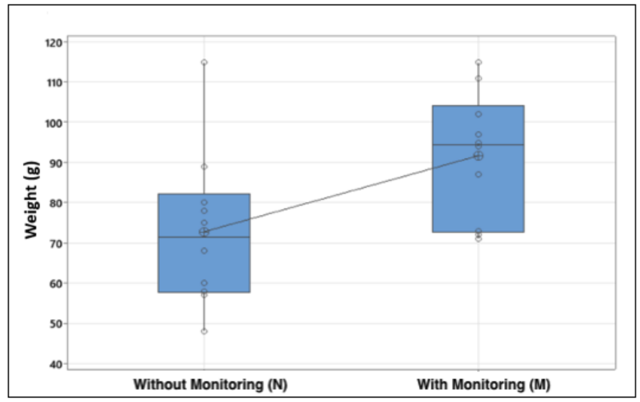


Figure 6: Weight distribution of without Monitoring and with Monitoring Gallus Domesticus breeds (T-test for 3th week)

The findings suggest that monitored chickens achieve significantly higher weights than unmonitored ones, regardless of breed. Furthermore, in this investigation, it was observed that Label Rouge chickens achieve a much higher weight in the same evaluation period when compared to *Gallus domesticus* breed chickens, regardless of whether or not they are being monitored.

We highlight that for a market demand focused on meat production, this percentage of weight gain becomes a key factor to be analyzed. Free-range poultry breeds such as Label Rouge, which are capable of achieving high productive potential, meat quality and good adaptability to a variety of climatic conditions, are key to achieving high yields production and satisfactory economic returns.

The *Gallus domesticus* breed does not have favorable genetic characteristics for high performance, which leads it to achieve notably lower weight gain averages when compared to a breed such as the Label Rouge. In light of this reality, it is worth reflecting that despite both breeds being considered to be the most produced in the study region, the reasons for this happening are different.

This issue is based on the premise that, while the *Gallus domesticus* bird is produced on many small properties in the region for family consumption, due to its high rusticity and dual-purpose characteristics, it is not commonly produced on properties that aim to sell meat on a large scale, precisely because it has low production potential. The Label Rouge breed, on the other hand, despite not being suitable for dual-purpose production, has a high meat production potential and equally good resistance to climatic variations.

The results obtained in this research have three main implications to be discussed. Firstly, the automated system tends to provides a healthier and more conducive environment for the chickens, resulting in greater weight gain.

Subsequently, it is worth noting that for small-scale producers, especially those targeting the sale of free-range poultry meat, are advised to choose to invest in genetically improved poultry for this purpose, such as the Label Rouge breed, as it is demonstrated better productive performance based on the data collected analysis.

Lastly, when we analyze the combination of a breed with good productivity potential like Label Rouge along with a monitoring system that provides thermal comfort and humidity control throughout its growth, there is a synergistic effect on overall production. The chickens that developed under these conditions showed the best weight gains among all the chickens analyzed.

Findings of RQ1:

- Automated systems for controlling environmental variables tend to enhance weight gain in poultry production. However, this improvement may be observed at different stages of growth, depending on the species.
- Our results suggest that the monitored chickens achieved an average weight that is 20% higher than the non-monitored ones.

4.1.2 Average Weight Increase vs. Total Feed Consumption (RQ2). This section examines the impact of automated monitoring system on poultry production, focusing on weight gain and feed consumption. Firstly, the weight gain of each chicken of the *Gallus domesticus* breed was analyzed for all weeks. Table 1 presents the individual weight chicken without monitoring (N) and with monitoring (M) over the five weeks of the experiment.

Table 1: Individual analysis of *Gallus Domesticus* chickens

Without Monitoring (N)					
ChickenID	**Poultry Weight (g)**				
	1w	**2w**	**3w**	**4w**	**5w**
N01	44.0	80.0	115.0	173.0	247.0
N02	38.0	40.0	68.0	90.0	134.0
N03	40.0	47.0	80.0	146.0	200.0
N04	40.0	43.0	60.0	112.0	146.0
N05	40.0	47.0	75.0	115.0	173.0
N06	39.0	38.0	58.0	87.0	133.0
N07	35.0	36.0	57.0	86.0	127.0
N08	34.0	32.0	48.0	86.0	124.0
N09	41.0	59.0	78.0	128.0	198.0
N10	44.0	59.0	89.0	155.0	231.0
Total avg	39.5	48.1	72.8	117.8	171.3
With Monitoring (M)					
ChickenID	**Poultry Weight (g)**				
	1w	**2w**	**3w**	**4w**	**5w**
M01	38.0	61.0	97.0	155.0	217.0
M02	34.0	51.0	73.0	102.0	147.0
M03	43.0	63.0	111.0	166.0	233.0
M04	40.0	63.0	102.0	163.0	220.0
M05	34.0	49.0	87.0	130.0	169.0
M06	33.0	47.0	72.0	92.0	133.0
M07	36.0	55.0	94.0	133.0	181.0
M08	46.0	74.0	115.0	175.0	235.0
M09	39.0	61.0	95.0	144.0	202.0
M10	32.0	47.0	71.0	-	-
Total avg	37.5	57.1	91.7	140.0	193.0

Among unmonitored chickens, 8 out of 10 showed weight gain between the first and second weeks, with 5 achieving increases of 15% to 45% (e.g., chicken N01). However, we observed that 2 out of the 10 chickens experienced a weight loss of 2% and 6%, corresponding to chickens N06 and N08 respectively.

One of the possibilities that could potentially explain this initial loss is related to the chickens' adaptation to a new environment. This thesis is supported by the fact that, in their early life phase (between 1 and 28 days), chickens face difficulties in adaptation since their thermoregulatory system is not yet fully developed [2]. After the initial adaptation phase, it was observed that there was a linear weight gain for these chickens, and no more weight loss due to stress throughout the experiment.

All monitored chickens showed weight gains, ranging from 42% (chicken M06) to 60% (chickens M01 and M08). It is also worth noting that no weight loss was observed in any chickens analyzed during this period. Therefore, the thesis emphasizing the influence of adaptation to the climatic conditions in the environment they were placed in is reinforced.

At the same time, we analyzed the weight gain of each Label Rouge chicken every week. Table 2 presents the individual weights of chickens without monitoring (N) and with monitoring (M) over the five weeks of the experiment.

Table 2: Individual analysis of Label Rouge chickens

Without Monitoring (N)					
ChickenID	**Poultry Weight (g)**				
	1w	**2w**	**3w**	**4w**	
N01	44.0	58.0	95.0	154.0	253.0
N02	55.0	95.0	216.0	423.0	618.0
N03	48.0	76.0	154.0	279.0	395.0
N04	52.0	88.0	179.0	320.0	470.0
N05	45.0	69.0	146.0	270.0	361.0
N06	53.0	93.0	211.0	418.0	610.0
N07	48.0	80.0	165.0	295.0	412.0
N08	43.0	56.0	92.0	132.0	198.0
N09	48.0	79.0	159.0	285.0	404.0
N10	53.0	89.0	188.0	361.0	524.0
Total avg	48.9	78.3	160.5	293.7	424.5
With Monitoring (M)					
ChickenID	**Poultry Weight (g)**				
	1w	**2w**	**3w**	**4w**	**5w**
M01	53.0	91.0	246.0	490.0	766.0
M02	52.0	87.0	220.0	417.0	657.0
M03	48.0	67.0	141.0	335.0	541.0
M04	53.0	103.0	267.0	510.0	780.0
M05	48.0	74.0	151.0	340.0	556.0
M06	42.0	65.0	140.0	249.0	392.0
M07	52.0	85.0	216.0	389.0	597.0
M08	48.0	85.0	184.0	296.0	489.0
M09	38.0	61.0	92.0	133.0	247.0
M10	52.0	89.0	230.0	446.0	705.0
Total avg	48.6	80.7	188.7	360.5	573.0

By conducting an intrinsic comparative analysis of the first three weeks of the experiment involving the Label Rouge breed, it is possible to observe that ***there was a minimal difference between the chickens with monitoring and those without monitoring. However, the monitored chickens' averages were slightly higher***. However, when observing the averages for the 4th week and especially the 5th week, ***a significant increase in the averages are noted, with a difference of 22% between the two environments in the 4th week and 35% in the 5th week.***

We highlight that the Label Rouge breed is considered one of the most climate-resistant in the country, which allows chickens of this breed to develop with good adaptability to various climates [3].

During the data collection period, it was possible to observe, through the daily behavioral assessment of the chickens a considerable improvement in the welfare of those that were under the monitoring system compared to the others. This result was due to the reduction in the signs of fatigue and discomfort typically observed in chickens in environments with temperature and humidity fluctuations outside of the ideal range.

When observing the feed consumption data presented in 7(a) and (b), we noticed that without monitoring *Gallus Domesticus* chickens, despite having a lower development in weight gain, obtained the highest average feed intake. Therefore, a greater quantity of feed is provided for a lower weight conversion rate.

Figure 7: Consumption plots for *Gallus Domesticus* Breed

The chicken's genetics may influence on this result, given that the *Gallus domesticus* breed is known for its low productivity and low feed conversion rates. In addition, when the chickens were subjected to uncontrolled environmental conditions, there was an exacerbation of this worsening in feed consumption and, consequently, in weight gain, leading to greater feed wastage.

Another point to be taken into account in this analysis is the mortality of chicken M10 in the 4th week (Table 1). With the loss of one of the animals in the treatment, the overall average of the batch in the 4th and 5th weeks remained higher when compared to the averages presented in the 7 (a) and (b).

This fact reinforces the discovery 1 mentioned earlier in this study, since, due to the controlled and healthy environment in which these birds were kept during data collection, it allowed them to achieve an overall higher weight gain in all the weeks analyzed. This issue highlights the importance of temperature and humidity quality in the production sector.

When observing the feed consumption data presented in 8 (a) and (b), we can see a more balanced feed consumption and weight gain among the Label Rouge breed birds. Those that had the highest average weight gain averages also had higher consumption throughout the experiment.

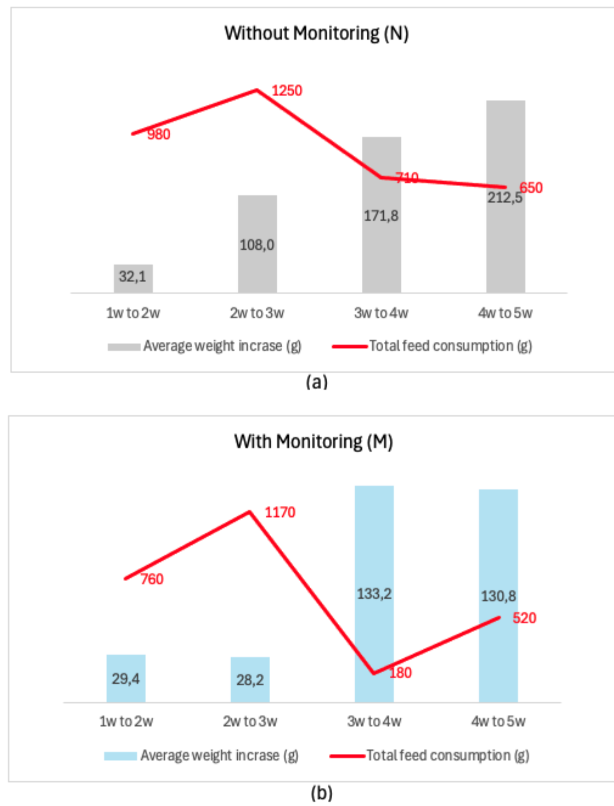


Figure 8: Consumption plots for Label Rouge Breed.

Findings of RQ2:

- Breeds with higher productive potential and great adaptability to climatic variations, such as Label Rouge, are the most suitable for regions with high temperatures.
- High-productivity breeds like Label Rouge, when subjected to ideal environmental conditions for their development through monitoring, achieve the highest productivity rates and provide better profitability.

4.1.3 Comparing the results obtained with a well-established poultry weight benchmark (RQ3). Table 3 presents a comparison of the weight averages focusing on the 4th and 5th weeks, of the Label

Rouge breed with the Extension Bulletin on Breeding Free-Range Birds [1]. Chickens raised without climate control had lower weight averages than expected. Chickens raised with the monitoring system exceeded expected weight averages between days 21 and 28.

Table 3: Label Rouge Parameters vs. Benchmark [1]

Age	Sample		Benchmark
	Without Monitoring (N)	With Monitoring (M)	-
21 days	293.7(g)	360.5(g)	350.0(g)
28 days	424.5(g)	573.0(g)	540.0(g)

Therefore, if we take the Bulletin presented by [1] as a parameter for ideal averages of bird weight per day of life, we note that birds not under a monitoring system reached lower than ideal averages, both at 21 days and at 28 days of life. In turn, when we compare the bulletin with the birds under the monitoring system, it is observed that the birds achieved higher weight gain averages in both collections. Thus showing the clear difference in weight gain of birds when subjected to different environments, that is, birds in ideal conditions, and birds that were not subjected to adequate monitoring and climate control.

Findings of RQ3:

- The results indicate that the adoption of the IS leads to improved production outcomes, aligning with established benchmarks, and offers significant potential for enhancing poultry management practices.

4.2 Results from the Interview (RQ4)

To address the first research question (Section 3), a small-scale Brazilian poultry producer was interviewed about their experience with the IS after the experiment.

Table 4: Participant's perception of how the platform works

Question	Participant's Answer*
I trusted the system and the information it displayed	Normally
The system is easy to understand and easy to use	Always
Information about environment variables was clear and easy to view	Always
The information displayed on the system was relevant to you	Always
The decision-making process regarding bird monitoring was relevant	Normally
Email alerts regarding temperatures above or below were relevant	Normally
The temperature and humidity variation graphs were relevant	Normally

*Scale of possible answers: Never, Sometimes, Normally, and Always

We also applied the interview questionnaire with two open questions that we will discuss in the sequence.

- **Question:** *What is your perception of IS contributions in poultry handling?* – This question aims to capture the potential of the IoT information system in terms of the results obtained and the effort spent in poultry handling from the small-scale Brazilian poultry producer's perspective.

Regarding the results obtained in production and whether the system helped in monitoring, the producer mentioned:

> *It was much more comfortable since with the monitoring I knew what was happening, so it was more relevant. It gave more security knowing what was happening through the system.*

Regarding the contribution to the well-being of poultry, we have the following answer:

> *Yes, it contributed because through the system we knew that they were not cold, they did not suffer from low temperatures, so it contributed a lot.*

- **Question:** *What are your suggestions for improving the IS in poultry handling?* – This question aims to capture the necessary improvements to be implemented and evaluate the system from the small-scale Brazilian poultry producer's perspective.

Regarding the suggested improvements, the producer mentioned:

> *Greater protection for the wires, as poultry kept pecking at the sensors and wires. Greater robustness for the equipment.*

Regarding the need for new information, the producer responded:

> *The poultry house needs to worry about temperature and humidity and the system provided this information, so it wouldn't need anything additional, especially for the chick stage.*

Regarding the general evaluation of the system, the producer mentioned:

> *It was productive, as it was more convenient and I avoided inspections at night, which is the most critical period and the system provided the necessary information. Giving me security and there was no need for me to be present in these situations. So it was positive.*

Based on the data obtained in the interview with the small-scale Brazilian poultry producer, we observed an improvement in the management routine was observed. With the software at hand, the producer no longer needed to visit the aviary several times a day to check for bird discomfort.

This change improved the daily work time management, and prevented trips to the aviary at inconvenient times (such as going to the aviary in the middle of the night on colder days to check if the chickens were not cold). Therefore, it is important to highlight the discussion of these aspects, as climate control within the aviary, regardless of the increase in profitability, provides a better quality of life for both the chickens and the producer's production routine.

Findings of RQ4:

- The system's automation proposes to significantly reduce the need for manual monitoring, offering substantial labor savings and operational efficiency, especially advantageous for small-scale poultry producers.

5 Threats to Validity

Construct Validity: we followed strict guidelines [18] in order to elaborate the interview protocol and artifacts. Two authors reviewed all procedures to ensure the validity and relevance of the questions. For the controlled experiments, we selected the producer with the most extensive experience in poultry farming to ensure relevance and encourage broader participation in future studies.

Internal Validity: The interview was conducted on the farmer's property to ensure they felt comfortable responding to the questions. We provided instructions and clarified the farmer's questions before completing the interview questionnaire. Thus, we expected to ensure that the farmer understood each interview question. In the controlled experiments, the loss of one monitored chicken in the fourth week, due to an attack by a domestic animal, may have influenced the results. The mortality of this bird directly affected the final data proportion, significantly reducing the overall average for the treatment of monitored *Gallus domesticus* chickens.

Conclusion Validity: A thematic or grounded theory analysis was not conducted for the interviews due to the single participant. For the controlled experiments, we used descriptive analysis methods, including bar graphs, percentages, and boxplot distributions.

External Validity: The study was conducted with only one producer, limiting the findings' generalizability. To address this limitation, we selected a producer with extensive experience in poultry farming. Furthermore, controlled experiments were conducted with two different chicken breeds to enhance the robustness of the findings.

6 Final Remarks

The main contribution of this paper was twofold: prescriptive, showing the architecture of an IoT-based Information System (IS) used for poultry raising, and descriptive, reporting results of a controlled experiment. Combined with poultry breeds possessing high productivity potential, integrating automated environmental control systems generates synergistic benefits for overall production. The monitored chicken exhibited accelerated growth and likely enjoyed superior health outcomes due to the stable environmental conditions maintained by the IS. Although the magnitude of improvement may vary across different growth phases and poultry species, the observed positive trend underscores the potential for enhancing poultry production through IoT-driven automation.

However, while the study demonstrates promising results, several avenues for future research emerge. First, further experimentation with larger sample sizes and extended monitoring periods would provide more robust data to generalize these findings across poultry breeds and growth stages. Additionally, future studies could explore the IS's adaptability to diverse climatic conditions and its effectiveness in managing other critical environmental factors such as humidity, air quality, and lighting, which also impact poultry health and productivity.

Moreover, research could investigate the possibility of integrating machine learning algorithms for predictive maintenance, health monitoring, feed optimization, and climate control. In other words, predictive adjustments based on historical data could further improve environmental management by anticipating climate fluctuations or animal behavior. Research could also investigate the cost-benefit analysis of the IS implementation on various scales of poultry farming, offering insights into the economic viability for both small-scale and large-scale producers.

Acknowledgments

We thank PrP/UEG and FUNAPE/UFG for the financial support to conduct this research.

References

[1] Luiz Fernando Albino and Mauro de Souza Godoi. 2016. *Extension Bulletin n. 51: Free-Range Chicken Farming (Boletim de Extensão Nº 51: Criação de Galinhas Caipiras) [In Brazilian Portuguese].* Technical Report. Extension Division, Technology Diffusion Center, Federal University of Viçosa (UFV).

[2] Tahere Amjadian and Mohammad Hossein Shahir. 2020. Effects of repeated thermal manipulation of broiler embryos on hatchability, chick quality, and post-hatch performance. *International Journal of Biometeorology* 64, 12 (2020), 2177–2183.

[3] Angela Maria Fortes de Andrade, Marcelo Bastos Cordeiro, Henrique Jorge de Freitas, and Reginaldo da Silva Francisco. 2019. Frangos de corte de linhagens pescoço pelado e carijó, criados sob condições de estresse térmico revisão de literatura. *Arq. Ciênc. Vet. Zool. UNIPAR (Online)* (2019), 119–125.

[4] Victor Basili and H Rombach. 1988. The TAME project: Towards improvement-oriented software environments. *IEEE Transactions on Software Engineering (TSE)* 14, 6 (1988), 758–773.

[5] Renata Mendes de Araujo, Marcelo Fornazin, and Mariano Gomes Pimentel. 2017. Uma Análise sobre a Produção de Conhecimento Científico nas Pesquisas Publicadas nos Primeiros 10 anos da iSys (2008-2017). *Braz. J. Inf. Syst.* 10, 4 (2017), 45–65. https://doi.org/10.5753/ISYS.2017.351

[6] Alan R Dennis and Joseph S Valacich. 2001. Conducting experimental research in information systems. *Communications of the association for information systems* 7, 1 (2001), 5.

[7] Valdemar Vicente Graciano Neto and Mohamad Kassab. 2023. *What Every Engineer Should Know About Smart Cities.* CRC Press - Taylor & Francis. 1st Edition. 254 p..

[8] Valdemar Vicente Graciano Neto, Mohamad Kassab, Vinicius Carvalho Lopes, Roberto Oliveira, and Renato Bulcão Neto. 2022. The State of IoT for Agribusiness in Brazil. *Computer* 55, 12 (2022), 140–144. https://doi.org/10.1109/MC.2022.3205934

[9] Shirley Gregor and Alan R Hevner. 2013. Positioning and presenting design science research for maximum impact. *MIS quarterly* (2013), 337–355.

[10] Flávio E. A. Horita, João Baptista, and João Porto de Albuquerque. 2023. Exploring the use of IoT Data for Heightened Situational Awareness in Centralised Monitoring Control Rooms. *Inf. Syst. Frontiers* 25, 1 (2023), 275–290. https://doi.org/10.1007/S10796-020-10075-8

[11] Heinz K Klein and Michael D Myers. 1999. A set of principles for conducting and evaluating interpretive field studies in information systems. *MIS quarterly* (1999), 67–93.

[12] Vinícius C Lopes, Roberto Felício de Oliveira, and Valdemar Vicente Graciano Neto. 2021. Towards an IoT-Based Architecture for Monitoring andAutomated Decision-Making in an Aviary Environment. In *Congresso Brasileiro de Agroinformática (SBIAGRO).* SBC, 320–328.

[13] Valdemar Vicente Graciano Neto, Flávio E. A. Horita, Everton Cavalcante, Adair José Rohling, Jamal El Hachem, Daniel Soares Santos, and Elisa Yumi Nakagawa. 2018. A Study on Goals Specification for Systems-of-Information Systems: Design Principles and a Conceptual Model. In *Proceedings of the XIV Brazilian Symposium on Information Systems, SBSI 2018, Caxias do Sul, Brazil, June 04-08, 2018*, Clodis Boscarioli, Carlos Alberto Costa, Scheila de Avila e Silva, and Daniel Luis Notari (Eds.). ACM, 21:1–21:8. https://doi.org/10.1145/3229345.3229369

[14] Willis W Shaner. 2019. *Farming systems research and development: guidelines for developing countries.* Routledge.

[15] Graeme Shanks et al. 2002. Guidelines for conducting positivist case study research in information systems. *Australasian Journal of Information Systems* 10, 1 (2002).

[16] Detmar Straub, Marie-Claude Boudreau, and David Gefen. 2004. Validation guidelines for IS positivist research. *Communications of the Association for Information systems* 13, 1 (2004), 24.

[17] Hailong Wang, Nanthi Bolan, Mike Hedley, and Dave Horne. 2006. Potential uses of Fluidised Bed Boiler Ash (FBA) as a liming material, soil conditioner and sulfur fertilizer. In *Coal Combustion Byproducts and Environmental Issues*, Kenneth Sajwan, Irena Twardowska, Tracy Punshon, and Ashok Alva (Eds.). Springer, 202–215.

[18] Claes Wohlin, Per Runeson, Martin Höst, Magnus C Ohlsson, Björn Regnell, Anders Wesslén, et al. 2012. *Experimentation in software engineering.* Vol. 236. Springer.